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TEXTBOOK OF
ANATOMY AND PHYSIOLOGY

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TEXTBOOK

OF

ANATOMY AND PHYSIOLOGY

BY

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PREFACE TO NINTH EDITION

In preparing this edition, material has been added, deleted, and rearranged both as to topics and more detailed matter.

Those illustrations which were not redrawn for the 8th edition have been redrawn, some new illustrations have been substituted for those in the previous edition, and fifteen new illustrations, some in color, have been added. The form and size of the book remain substantially the same.

Grateful acknowledgment is made to students who have contributed much to the contents of the book in the way of new material and suggestions for arrangement, to those students and teachers who through correspondence have greatly aided in all the work, and to Assistants both from the field of Biology and from the field of Nursing Education with whom I have been associated. I join Miss Gray in acknowledging the helpful coöperation of Mr. J. Norris Myers, Mr. J. P. Smith, and The Macmillan Company.

CAROLINE E. STACKPOLE

TEACHERS COLLEGE,
NEW YORK CITY
May, 1934

PREFACE TO EIGHTH EDITION

In a previous revision of this textbook, the aim was stated as follows: "It represents an attempt to describe in as simple a manner as possible the phenomena of life and the principal conclusions which have been reached as to their interdependence and cause." This aim has dominated the present revision.

A further aim has been to include the material outlined in the course in Anatomy and Physiology in the Curriculum published by the National League of Nursing Education. It would be flattering to think these aims have been achieved. It is highly probable that teachers and students will discover mistakes as well as many places where improvement is needed. Corrections or suggestions for improvement are always appreciated.

It is encouraging to be asked to incorporate new material and an attempt has been made to grant the requests that have come to the publisher and author. Obviously it is difficult to do this and keep the size of the book within reasonable limits. Two hundred fifty-five illustrations account for many pages.

A large proportion of the illustrations have been redrawn, while thirty new ones have been added.

In a text where much space is given to explanations of scientific terms and a very complete index is provided, it is a question whether a complete glossary is necessary. Students should be helped to form the habit of using the index. It is highly probable that the index will be more helpful than any glossary, because the limitations of space make a glossary as complete as the index an impracticable ideal.

The advisability of placing a list of reference readings at the end of each chapter has been considered. The principal sources of reference material are the scientific journals and textbooks for advanced students. It is doubtful whether the students for whom this book is intended are sufficiently prepared to profit by the study of scientific journals, and to list chapter or page references in advanced textbooks does not commend itself. New editions of such advanced texts are constantly coming out and chapter or page references that were correct at the time of publication may

easily be incorrect a few months later. Hence the bibliography on page 583 which represents a minimum of necessary reference books rather than a complete list.

Nothing is more encouraging than the growth of reference libraries in some Schools of Nursing. Many of them have outgrown the bibliography. Others are struggling to get along with so few reference books that the marvel is, not that some students fail, but that the majority do so well.

It is desirable to stimulate an open-minded questioning attitude and help students to realize that physiology is a growing subject constantly adding to its knowledge, and discarding old theories, or reinterpreting them in the light of experimental results. An appreciation of, and respect for, knowledge gained by careful detailed experiments can best be taught in connection with laboratory work. To teach Anatomy and Physiology by any but the laboratory method seems inexcusable. The fact that in many schools the laboratory method is used makes the question why all schools do not use it all the more pertinent.

Having been a student and teacher of anatomy and physiology for many years, the number of students and co-workers to whom I am indebted is very large. If it were practical to name all of them, my list would be a long one. It is a pleasure to acknowledge this indebtedness and express my appreciation of it. In connection with this revision I am especially indebted to Caroline E. Stackpole, A.M., Associate in Biology, Teachers College, New York, who has read and criticized my manuscript; Dr. George W. Corner of Rochester University, who helped with the preparation of Chapters III and XXIV; and Dr. R. J. E. Scott, who has again made the index. The representatives of The Macmillan Company, particularly Mr. J. Norris Myers and his staff, and Mr. J. P. Smith of the Manufacturing Department, have been most coöperative and helpful. The authors whom I have consulted and the various publishers who have granted me permission to use illustrations from their books have been most generous.

CAROLYN E. GRAY

CITY HOSPITAL,
NEW YORK CITY
September, 1931

CONTENTS

TEXTBOOK OF
ANATOMY AND PHYSIOLOGY

CHAPTER I

DEFINITIONS: CAVITIES AND REGIONS OF THE HUMAN BODY

Definitions.— This book discusses anatomy and physiology, knowledge that is essential as a basis for **hygiene,** the science of keeping well, and is equally essential in attempting to understand the pathological states that engage the attention of students of the science of medicine in their twofold effort to anticipate and forestall individual departure from normal, through **preventive medicine,** and to take measures necessary to bring sick individuals back to normal, as in **remedial medicine.**

The biological sciences run into large branches, — morphology, physiology, development or embryology, hygiene, etc.

Morphology is the branch that deals with structure and spatial relationships — the way bodies are built and put together, the kinds of material used and the architecture of the entire organism in action, — and, as such, is concerned with finding out the underlying principles of structure that provides for motion.

Under this head, **anatomy** is the science of gross, or macroscopic, structure; that which can be seen with the unaided eye.

There are many ways of looking at the subject of gross structure; in all of them one would be studying the same objects, but the point of view would be different. As in all the biological sciences, the focus of thought may be on the human being alone, in which case the study would be **human anatomy,** or it may be on comparing the structures of animals with each other and with the human structure, which would give **comparative anatomy.** There is also **systemic anatomy,** with a point of view slightly divergent from that of **regional anatomy,** the former putting attention on the systems of the body, the latter stressing regions, such as the abdomen, the thorax, the arm, or the head. Great advances of skill in physical diagnosis, brought about by the use of such methods as measurement, palpation, X-ray, transillumination, etc., made evident the need of regional anatomy and the conceptions it gives of the effects that changing conditions in one organ exert upon all other organs, as, for instance, when it becomes large and full through altered blood-supply and presses on nearby organs.

Again, anatomy may be looked at from the angle of function. **Functional anatomy,** the study of the interplay of organ upon organ as each continually changes in shape, size, temperature, pressure, and in other respects, is a dynamic rather than a static subject, and today, more than hitherto, anatomy is taken up with the structure of living, moving parts of the living animal.

Pathological anatomy has to do with diseased organs and structures, their location and regional effects.

Histology handles minute or microscopic structure, structure that can be seen only with the aid of lenses, and often, therefore, is defined as microscopic anatomy. It makes clear the arrangement of cells in tissues and the manner in which tissues are built into organs.

This can be studied as **normal histology,** dealing with healthy cells, tissues, and organs, and as **pathological histology,** dealing with the same parts when they are diseased. Early studies in histology were chiefly anatomical, and limited to the shapes and appearances of the tissues and cells, in the manner of **anatomical histology,** but modern histology, in making use of tissue-cultures, micromanipulation of living tissues, etc., is largely **physiological histology** and gives much attention to tissue development and tissue activities.

Physiology is the science of function and activity and shows what organs do in relation to each other and in the harmonious behavior of the organism as a unit. The investigation of these organic modes of behavior splits into many branches. There is **human physiology** and **comparative physiology,** the latter using information about the bodily working of plants and animals as compared with each other and with the human organs and systems. Another aspect is **general, or cellular physiology,** a term applied to the individual cells themselves, as they live out on a small scale all the activities that characterize the larger systemic units of the organism, — such activities as respiration, excretion, absorption of food, and movement. Two other aspects are **routine physiology,** which would be concerned with minute and always changing adjustments that have to be undertaken in and outside the body while the factors of the environment are within adjustable range, and **emergency physiology,** concerned with the adjustment of the activities of the organs when conditions surrounding them become dangerously harmful, as they become, for instance, when suddenly climate is extremely dry or wet or hot or cold, when water to drink is lacking, or when such notable events as fever, bruises, or cuts happen within the body.

Embryology in its widest sense means the science of growth from the one-cell stage to the adult, but frequently is restricted to mean the period of growth and development before birth. This period is followed by the development of infancy, adolescence, maturity, and old age.

Development can be studied as a strictly anatomical subject, but, recently, is being studied more and more from the standpoint of physiology.

Hygiene is defined as organized knowledge about the application of the principles of physiology to living in health, and is divided into many kinds. An example of two important divisions would be **external hygiene,** — by which is meant the preparation of the environment for the individual — and **internal hygiene,** — by which is meant the healthful reaction of the individual to environment.

External hygiene would cover such matters as good foods and the scientific preparation of the diet, ventilation, cleanliness in regard to all supplies and wastes, the conditions of workrooms in regard to light, heat, body posture, and opportunities afforded to change body position at will, and the arrangement of a daily program that gives interesting work, healthful recreation, and that does away with fatigue, worry, emotional friction, and other harmful elements.

Internal hygiene embodies knowledge of the adequate handling of supplies and wastes inside the body. The transformation of the periodic intake of supplies and outgo of wastes into the uniform state of constancy found in the body fluids is possible because the body has the ability to distribute, store, and redistribute according to the varying general and local needs of the body.

These sciences and others, including psychology, sociology, etc., can be grouped as the **biological sciences,** having to do with living things, as contrasted with the **physical sciences,** that have to do with not living matter, — astronomy, physics, mathematics, etc. All of these make up **science.** The branches of science are all closely related and overlap. Science is one thing: it is broken into separate sciences for convenience and to emphasize different or more items than would be possible if handled as a whole.

Cavities. — The distinguishing anatomical character of all *vertebrate animals* is the presence in the trunk of a vertebral column which separates a dorsal and a ventral cavity.[1]

[1] It will be noticed we are using the term *cavity* in different senses. For instance, in one sense in reference to the internal cavities, the dorsal, thoracic, and abdominal; and in a more general sense to the more open cavities, such as the orbital, nasal, and buccal cavities.

The dorsal cavity. — The dorsal cavity is continued through the neck into the head and there widens out to form the cranial cavity. It is a complete bony cavity formed by the bones of the skull (cranial) and the bones of the spine (vertebræ). It is lined by the meninges of the brain and spinal cord.

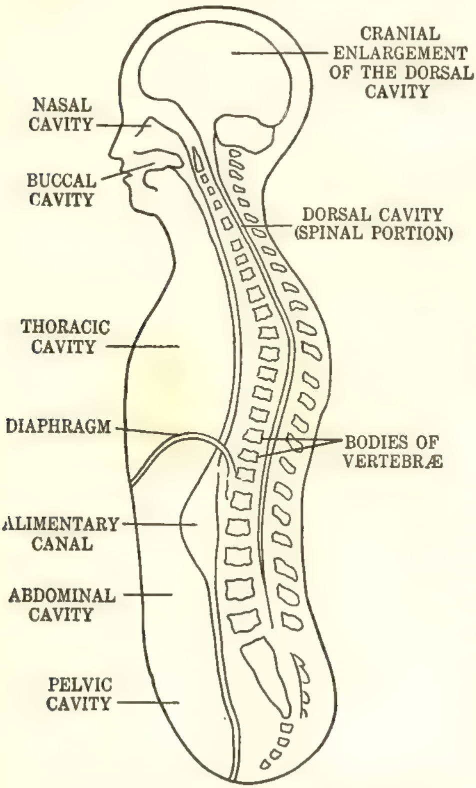


FIG. 1. — DIAGRAMMATIC LONGITUDINAL SECTION OF THE TRUNK AND HEAD. The alimentary canal is represented running through the whole length of the ventral cavity, but is shortened and straightened for the sake of simplicity.

(1) *The cranial cavity* contains the brain.

(2) *The spinal cavity* is continuous with the cranial cavity and contains the spinal cord. The spinal cord is continuous with the brain.

The ventral cavity. — The ventral cavity is not a complete bony cavity. The wall of this cavity, the so-called body-wall, is composed of skin, connective tissue, muscles, and serous membrane. In mammals it is subdivided by the diaphragm into two main cavities, the thoracic and abdominal.

(1) *The thoracic cavity*, or chest, contains the trachea or windpipe, the lungs, esophagus or gullet, heart, and the great vessels springing from, and entering into, the heart.

The thoracic cavity is lined with pleura which divides it into right and left *pleural cavities*, each containing a lung. The other thoracic organs lie in the *mediastinum* between these pleural cavities.

The **diaphragm** is a dome-shaped musculo-membranous partition between the thoracic and abdominal cavities.

(2) The *abdominal cavity* contains the stomach, liver, gall-bladder, pancreas, spleen, kidneys, small and large intestines.

The abdominal cavity is lined with the peritoneum, forming the *peritoneal cavity*. The kidneys are described as being retroperitoneal, lying, as they do, behind the peritoneum.

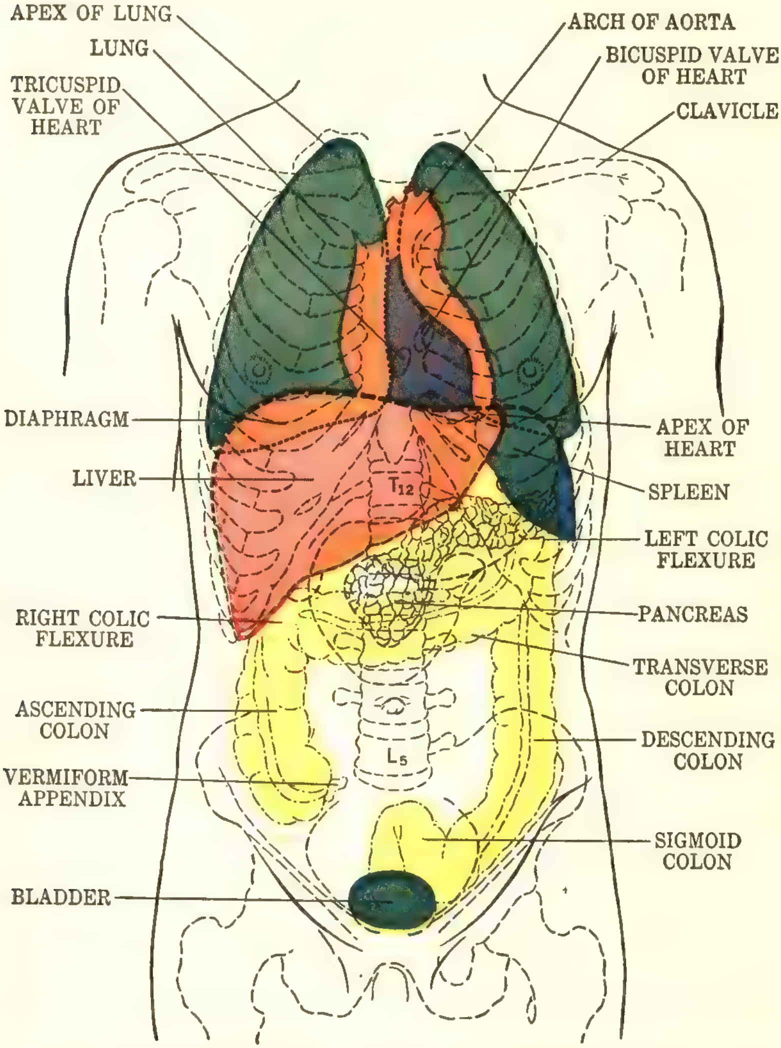


FIG. 2. — Surface projection of the abdominal and thoracic viscera, showing the average vertebral levels of organs. Ventral view. T 12, twelfth thoracic vertebra; L 5, fifth lumbar vertebra. The lungs overlap the heart; the area of overlapping is tan color, in the diagram, because green and purple make tan. (*Hand-Atlas of Clinical Anatomy* by A. C. Eycleshymer and T. S. Jones. Courtesy of Lea and Febiger.)

The *pelvic cavity* is that portion of the abdominal cavity lying below an imaginary line drawn across the prominent crests of the

hip bones. It is more completely bounded by bony walls than the rest of the abdominal cavity. It is divided by a narrow bony ring — pelvic inlet — into the greater or false pelvis above, and the lesser or true pelvis below. The lesser or true pelvis contains the bladder, rectum, and some of the generative organs.

A survey of the skeleton shows small cavities in the skull, in addition to the cranial cavity, which for the sake of simplicity in study are included here.

The orbital cavities contain the eyes, the optic nerves, the muscles of the eyeballs, and the lacrimal apparatus.

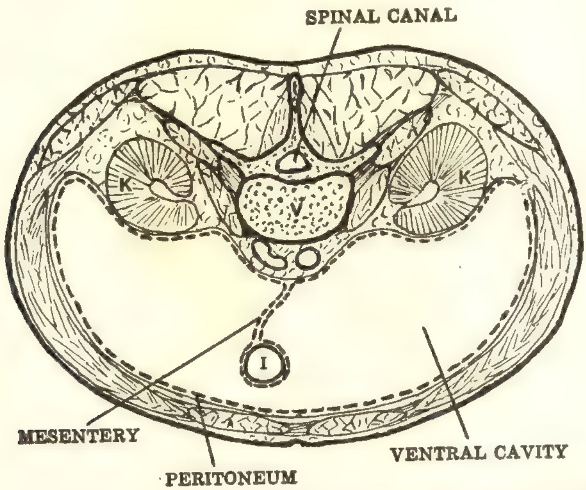


FIG. 3. — DIAGRAM. Transverse section of body, showing ventral and dorsal cavities. *I*, small intestine; *K*, kidney; *V*, vertebra. The vena cava and aorta are shown below the vertebra.

The nasal cavity is filled in with the structures forming the nose.

The *buccal cavity* or mouth cavity contains the tongue and teeth.

It is helpful to consider the human body as comparable to a community which is divided into localities or districts, these districts being given distinctive names. Furthermore we may think of this community as made up of industrial units, each one carrying on special work, but dependent upon and coöperating with all the other units, the arrangement and location of each being determined by the efficiency of the whole. In order to understand any such coöperative community it would be necessary to study (1) the different districts, (2) the industrial units and their subdivisions, (3) the structure, and (4) the functions of each unit.

Figs. 5 and 6 are worthy of careful study, as the regions (districts) of the body are labeled.

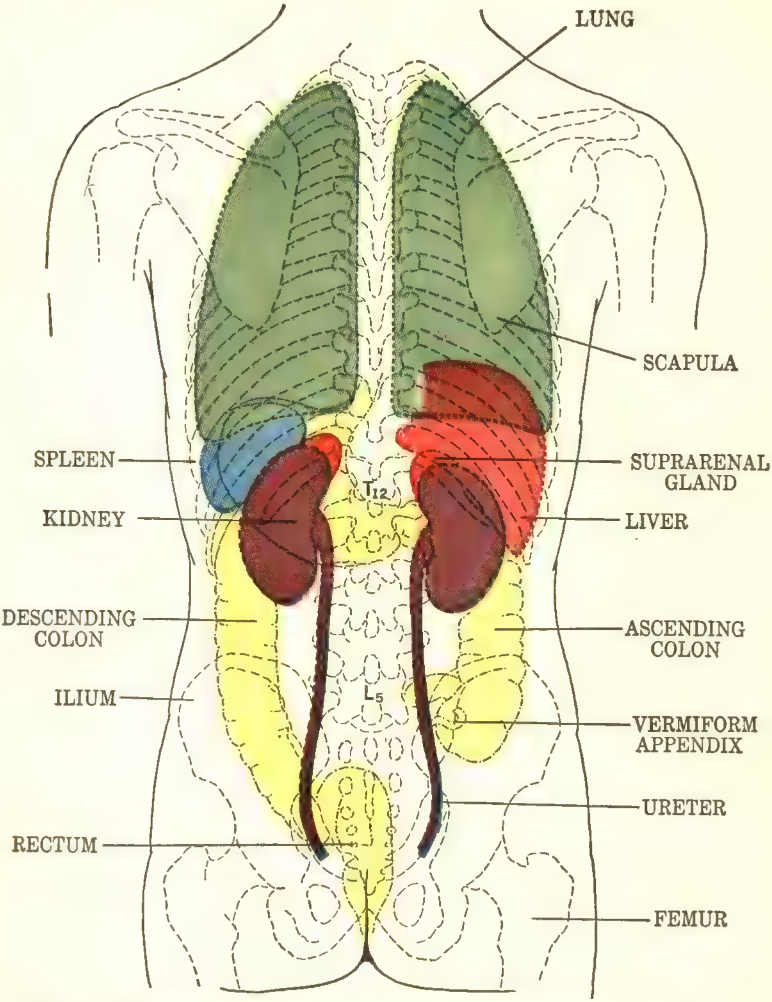


FIG. 4. — Surface projection of the abdominal and thoracic viscera, showing the average vertebral levels of organs. Dorsal (posterior, back) view. T 12, twelfth thoracic vertebra; L 5, fifth lumbar vertebra. (*Hand-Atlas of Clinical Anatomy* by A. C. Eycleshymer and T. S. Jones. Courtesy of Lea and Febiger.)

Due to the fact that man walks erect and the majority of mammals go on all fours, confusion is apt to arise in the use of terms used to describe corresponding parts of man and other animals. To avoid this confusion anatomists have given these terms arbitrary significance.

The anatomical position. — In describing the body, anatomists always consider it as being in the erect position, with the face toward the observer, the arms hanging at the sides, and the palms of the hands turned forward.

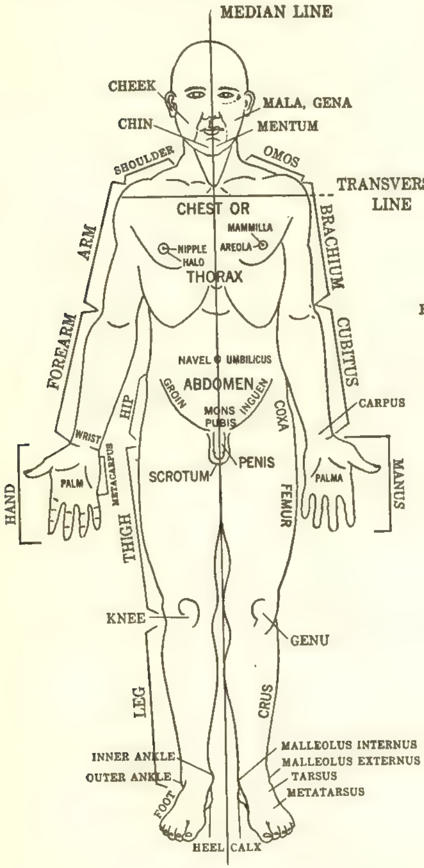


FIG. 5. — Front view.

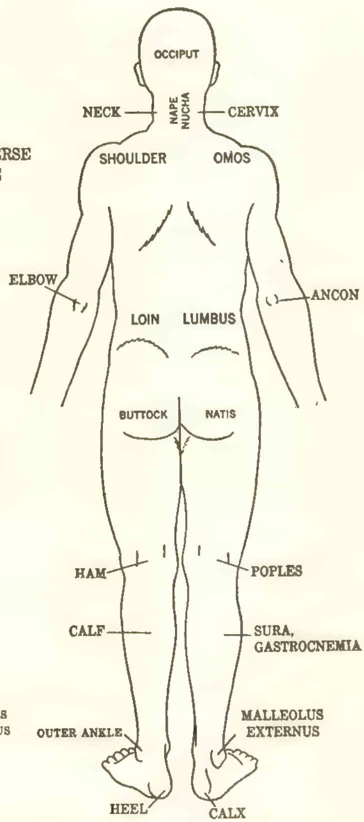


FIG. 6. — Back view.

THE ANATOMICAL POSITION. The parts are labeled in English on one side and in Latin on the other side.

Comparative anatomists call the head end of an animal or man *anterior*,[2] the opposite end *posterior*, the side containing the backbone *dorsal* and the opposite side *ventral*. Textbooks of human anatomy use both *dorsal* and *posterior* for the side containing the backbone, and *ventral* or *anterior* for the opposite side. The head

[2] The terms *anterior*, *posterior*, *ventral*, and *dorsal* are used in this book. For B. N. A. terminology see *Anatomical Terminology* by Lewellys F. Barker, published by P. Blakiston's Son & Co.

end is also spoken of as *superior*, and the opposite end *inferior*. The terms *cephalic* and *caudal* are sometimes used as synonymous with superior and inferior.

The median or sagittal line. — This refers to an imaginary line drawn through the middle of the body, from the top of the head through the sagittal suture (see Fig. 5) to the floor at a middle line between the feet, dividing the body into right and left halves. The parts nearest this line are described as *mesial*, the parts farthest from this line are described as *lateral*.

Internal and external are reserved almost entirely for describing the walls of cavities or of hollow viscera.

Proximal is used to describe a position near the source of any part. *Distal* is used to describe a position distant, or farthest away from the source of any part. Thus we speak of the proximal end of a finger and the distal end of a finger.

Parietal (from *paries*, a wall) is used to describe the walls enclosing the body cavity or surrounding the organs.

Visceral (from *viscus*, an organ) is applied to the organs within the body cavities.

In anatomy the term *periphery* means the outside or surface of a body or an organ.

SUMMARY

Biological Sciences deal with living things
- Morphology structure
  - Anatomy — macroscopic structure
  - Histology — microscopic structure
- Physiology — function
- Development growth
  - Morphological
  - Physiological
  - Embryology — early growth and development

Anatomy
- Human
- Comparative
- Systemic
- Regional
- Functional
- Pathological

Histology
- Anatomical
- Functional
- Pathological

Physiology
- Human
- Comparative
- General or Cellular
- Routine
- Emergency

Embryology
- Morphological
- Physiological

Hygiene
- Definition
- External
- Internal

Science is concerned with demonstrated and observed facts systematically arranged.

HUMAN BODY
- **Dorsal Cavity**
  - 1. **Cranial cavity** — Brain
  - 2. **Spinal canal** — Spinal cord
- **Ventral Cavity**
  - 1. **Thoracic cavity**
    - Esophagus — Trachea
    - Lungs — Heart
    - Blood-vessels
  - Right and left pleural cavities lined with pleura, each contains a lung.
  - The mediastinum between cavities contains trachea, esophagus, heart, and large blood-vessels.
  - The diaphragm separates the thoracic and abdominal cavities.
  - 2. **Abdominal cavity**
    - Stomach — Spleen — Pancreas
    - Liver — Gall-bladder
    - Kidneys
    - Large and small intestines
    - Pelvic cavity (Lower portion abdominal cavity)
      - 1. Greater or false pelvis
      - 2. Lesser or true pelvis
      - Bladder — Rectum
      - Some of the reproductive organs
  - Peritoneal cavity lined with peritoneum, contains organs as above, except kidneys, which lie between peritoneum and spinal column — retroperitoneal in position — and organs of true pelvis.
- **Facial Aspect of Skull**
  - 1. **Orbital cavities**
    - Eyes. Optic nerves
    - Muscles of the eyeballs
    - Lacrimal apparatus
  - 2. **Nasal cavity** — Structures forming the nose
  - 3. **Buccal cavity**
    - Tongue
    - Teeth

Anatomical Position
- Definition
- Anterior, posterior, dorsal, ventral
- Superior, inferior; cephalic, caudal
- The median or sagittal line
- Proximal, distal
- Parietal, visceral
- Peripheral

CHAPTER II

SYSTEMS, ORGANS, TISSUES, CELLS

One way of studying the human body is to analyze it into its component parts, from organism to systems, organs, tissues, and cells.

System. — An arrangement of organs closely allied to each other and concerned with the same function is called a *system*. Nine systems are found in the human body. Their names, the organs of which they consist, and the functions of each are briefly expressed as follows.

Skeletal system. — This system consists of the bones of the body. The ~~main functions are support and protection~~.

Muscular system. — This system consists of the voluntary muscle trunks (~~*e.g.*, biceps muscle)~~ and the involuntary muscles (~~*e.g.*, arrector pili muscles~~), and the main function is to cause motion by contracting.

Nervous system. — This system consists of the cerebrospinal system and the autonomic [1] nervous system. The main functions are to acquaint the organism with the environment and to control and insure coördination in the working of all the systems in the body. It contains the centers for all the sensations, intelligence, and thought that we recognize as the highest functions of life.

Vascular or circulatory system. — This system consists of the heart, blood-vessels and blood; lymphatics and lymph. The main function is to distribute body fluids steadily to all the cells, maintaining the lymph which bathes them in a "steady state" in all respects at all times.

System of internal secretions. — This system [2] consists of the ductless glands. It includes the thyroid gland, parathyroids, thymus, adrenals, pituitary body, pineal body, and portions of the glands with ducts, such as the islands of Langerhans in the pancreas, portions of the ovaries and testes as well as the liver. There is much evidence to support the theory that every cell is a ductless gland.

[1] For subdivisions of the nervous system, see Chapter VIII.

[2] This is not always counted as a separate system but as part of the other systems. Such a classification shows eight biological systems.

The function of this system is to contribute substances to the blood stream which affect the activity of the body cells.

Respiratory system. — This system consists of the nose, pharynx, larynx, trachea, bronchi, and lungs. The main functions are to provide oxygen and get rid of excess carbon dioxide.

Digestive system. — This system consists of the digestive canal and the accessory glands, *i.e.*, the salivary glands, the pancreas, and the liver. The functions are to receive, digest, and absorb food and eliminate some wastes.

Execretory system. — This system consists of the urinary organs, *i.e.*, the kidneys, ureters, bladder, urethra, an~~d in a limited sense the respiratory and digestive systems and~~ the skin.[3] The function is to eliminate the waste products that result from cell activity.

Reproductive system. — This system consists of the testes and their ducts in the male; the ovaries, uterine tubes, uterus, and vagina in the female. The function is to insure the continuance of the race by the production of other beings.

It is important to remember that these systems are closely interrelated and dependent on each other. While each forms a unit especially adapted for the performance of some function, that function cannot be performed properly without the assistance and coöperation of the other systems. The most perfect skeleton is not capable of support unless assisted by the muscular and nervous systems. Any interference with the circulatory system also affects the work of the excretory system, etc.

Organ. — An organ is a physiological unit composed of two or more different tissues associated in performing some special function and especially adapted to the performance of that function. Systems are made up of smaller units or *organs*, with a corresponding division of labor, and special adaptation of the organ to its particular share of the work of the system. For example, the urine excretory system consists of the following organs:

Two kidneys, which form the urine by eliminating waste materials from the blood.

Two ureters, ducts which convey the urine from the kidneys to the bladder.

A bladder, a reservoir for the reception of urine.

An urethra, a tube through which the urine passes from the bladder and is finally voided.

The interdependence of these organs is obvious, and differences in structure suggest differences in function.

[3] For the skin and its work in excretion of heat, see Chapter XXII.

Tissues. — The organs can be analyzed into component *tissues.* For example, the stomach is composed of columnar epithelium, smooth muscle tissue, connective tissue, and serous tissue. Microscopic study of tissues reveals the fact that tissues are made up of

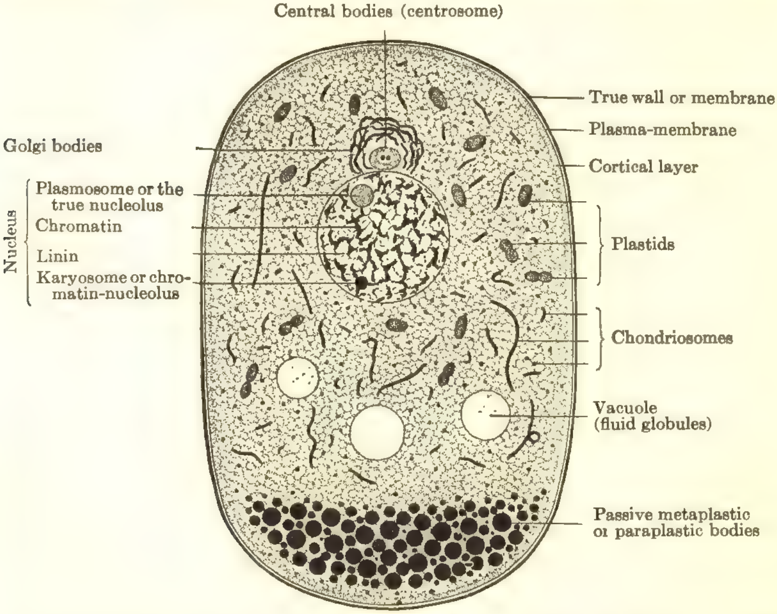


FIG. 7. — DIAGRAM OF A GENERALIZED CELL. The chromatin is also called *basichromatin* since it stains with basic dyes; the linin is called *acidichromatin* since it stains with acid dyes. The *Golgi bodies*[4] are usually found near the nucleus; though imperfectly known, they probably function in secretion. *Plastids* are areas of special chemical activity leading to the production of special substances, *e.g.*, starch grains in plant cells. *Chondriosomes* are thought to function in the production of germ cells.

smaller units or *cells,* and these cells are the ultimate physiological and structural units of the body.

Each tissue is a group of cells with more or less intercellular material. The intercellular material varies in amount, in composition, and in many cases determines the nature of the tissue, for example, muscle and bone.

Cells. — Due to the fact that the cells are physiological and structural units of the body, it is necessary to understand their activities and structure. Low down in the scale of life we find animals so simple that they are described as consisting of one cell. These unicellular animals are alive, because they are capable of carrying on the biological functions which are essential to life.

[4] Camillo Golgi, Italian anatomist, 1843–1926.

Briefly, these biological functions are support, breathing, digesting, collecting and distributing, moving, excreting, irritability to environment, and reproducing. The ameba, a typical one-cell animal, can be observed under the microscope carrying on these functions. The life of each individual cell in the body is dependent on its ability to carry on these functions.

As we ascend in the scale of life, we find animals that consist of a greater number of cells. The human being may properly be described as a multicellular animal consisting of an enormous aggregate of cells and intercellular material. In multicellular animals, individual cells are aften remote from air, food, and the excreting organs, and must rely upon the circulating fluids to carry air and food to them, and waste matters from them. The systems of the body represent an adaptation and specialization of groups of cells to carry on the biological activities for the body as a whole. A comparison of the biological activities of a unicellular animal with the biological activities of the cells of multicellular animals, and the functions performed by the systems of the body, show them to be essentially the same.

Structure of the cell. — A cell[5] is a minute portion of living substance enclosed in a cell membrane which is thin and delicate. The cell contains a nucleus, an oval or spherical body surrounded by its membrane. This in turn often contains one or more smaller bodies or nucleoli.

Protoplasm is a general term for living substance. The protoplasm of the cell-body exclusive of the nucleus is called *cytoplasm.* It varies in extent and in appearance in different cells, being sometimes homogeneous, sometimes alveolar, and sometimes granular in structure.

That portion of the protoplasm inside the nuclear membrane is called the *nucleus.* It consists of a fine network of material called *linin,* and on this are strung, so to speak, granules of a material called *chromatin.* Beside these granules of chromatin other masses are sometimes found which stain in a different manner and are called *nucleoli.* By studying the behavior of cells or parts of cells deprived of a nucleus and comparing this behavior with that of similar cells containing a nucleus, it has been demonstrated that the nucleus is essential for (1) the chemical changes on which the nutrition and functioning of the cells depend, (2) instigating the

[5] The word *cell* is from the Latin *cella* — a cavity — and was first used by Robert Hooke (1665) to designate the minute cavities separated by solid walls observed in cork. The name is not especially appropriate, but it is too firmly fixed in our language to be abandoned.

process by which cells multiply, and (3) in the chromatin of the nucleus constituting the material that transmits characteristics from parents to children. In a cell which is about to divide this chromatin becomes aggregated into bodies called *chromosomes*. The number of chromosomes is always constant for the same species, but varies for different species.

The term *central bodies* (centrosomes) is applied to structures, usually double, which are associated with many cell activities, particularly cell division. During mitotic division, and sometimes during the resting stage, the central bodies are surrounded by fibrillæ which radiate from them like the rays of the conventional sun.

In the meshwork of protoplasm various passive bodies are often suspended, such as food granules, pigment bodies, drops of oil, etc. These may represent reserve food material, or waste matters, and are non-living substances collectively designated as *metaplastic*, or *paraplastic* substances.

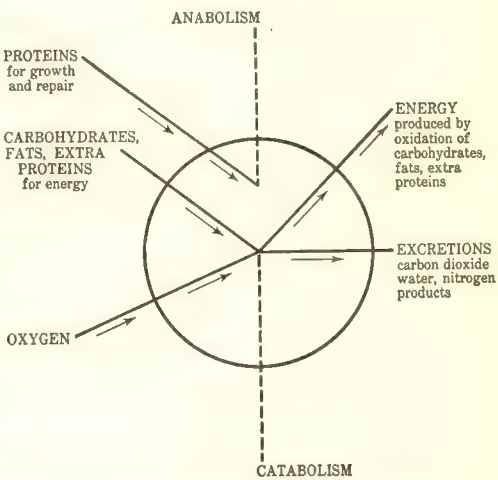


FIG. 8. — DIAGRAM SHOWING METABOLISM IN A CELL.

Life activities in cells. — In order to live each cell must be capable of carrying on the activities necessary to life. These may be summarized under the general term *metabolism*. The changes which involve the building up of living material within the cell have received the general name of *anabolic* changes, or *anabolism*; on the other hand, those which involve the breaking down of such material into other and simpler products are known as *catabolic* changes, or *catabolism*, while the sum of all the anabolic and catabolic changes which are proceeding within the cell is spoken of as the *metabolism* of the cell. These chemical changes are always more marked as the activity of the cell is promoted by warmth, electrical or other stimulation, the action of certain drugs, etc.

The activities exhibited by cells are (1) *Support.* — Each cell is

afforded support by the cohesiveness of its own structure; by the cell wall if one exists; if not, then the outer circumference of the protoplasm approximates the function of a membranous support.

(2) *Respiration.* — Each cell coming in contact with oxygen absorbs it. During this absorption some of the cell contents are oxidized, and as a result of this oxidation energy is liberated, and carbon dioxide, which is a waste product, is formed. The purpose of respiration is to furnish oxygen to each individual cell, and to take from the cell the excess carbon dioxide which it does not need.

(3) *Use of foods.* — Each cell is able to take to itself, and eventually convert into its own substance, certain materials (foods) that are non-living; in this way the protoplasm may increase in amount, or, in other words, the cell may grow. Foods may also be oxidized to yield energy and regulate body processes.

(4) *Motion.* — This is exhibited in two forms and is due to the ability of protoplasm to contract.

(*a*) *Ameboid movement* consists in the pushing outward by the cell of processes, called pseudopodia. These may be retracted or the contents of the cell may flow into them and change both its shape and position. By a repetition of this process the cell may move slowly away from its original situation, so that an actual locomotion takes place, *e.g.*, ameboid motion of white blood cells.

(*b*) *Ciliary movement* is the whipping motion possessed by minute hair-like processes called *cilia*, which project from the surface of some epithelial cells.

(5) *Circulation.* — This consists in a "streaming" of the protoplasm within the limits of the cell. By this means nutritive material or waste substances may be carried from one portion of the cell to another.

(6) *Excretion.* — Each cell is able to discharge and thus get rid of waste substances.

(7) *Irritability.* — Irritability is that property which enables a cell to respond to stimuli. If the stimulus received by a cell is strong enough, it is conducted throughout the protoplasm of the cell, and the cell responds. The response may take the form of an increase of some kind of activity, such as motion, growth, etc., or it may take the form of a decrease of these activities. If the response is an increased activity, the protoplasm is said to be *excited;* if the response is a decreased activity, the protoplasm is said to be *inhibited.*

(8) *Cell division.* — Like all living organisms, each cell grows and produces other cells. As the cells of the body are constantly wear-

ing out and leaving the body in the excretions, the need for constant reproduction of cells is apparent. Cells usually divide by indirect cell division, or *mitosis*. In mitosis the nucleus passes through a series of changes illustrated in Fig. 9. Chromatin is defined as that part of the nucleus which becomes colored when certain basic

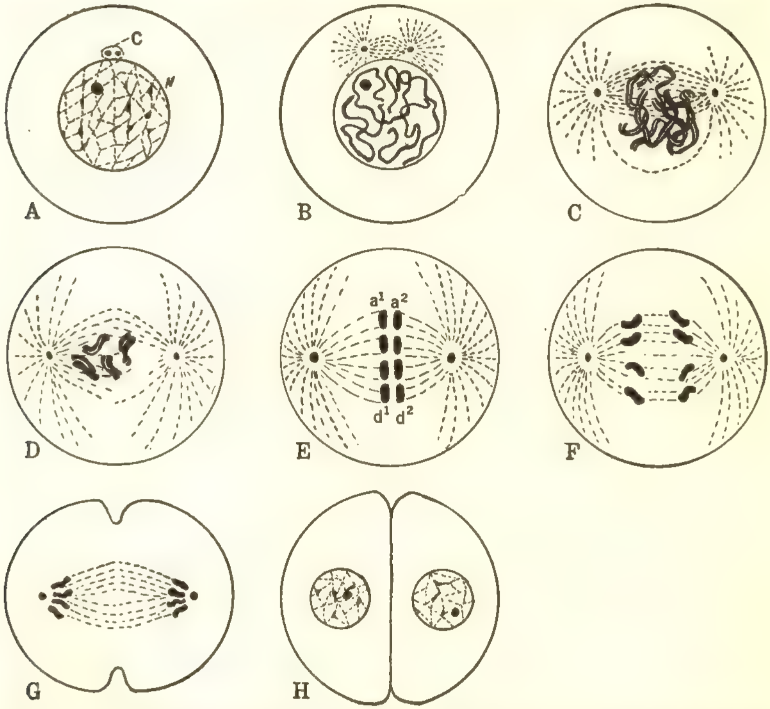


FIG. 9. — DIAGRAMS TO SHOW MITOSIS. The cell is presumed to have four chromosomes. *A*, resting cell with nucleus (*n*) and centrosome (*c*); a nucleolus and network of chromatin are shown in the nucleus. *B*, spindle fibers forming, chromatin being massed into chromosomes. *C*, nuclear membrane disappearing, chromosomes shown divided lengthwise into halves. *D*, chromosomes shorter and thicker, staining power increased. *E*, chromosomes arranged on the spindle, the two halves of each chromosome opposite each other as at a_1 and a_2, d_1 and d_2, etc. *F*, chromosomes moving toward the poles of the spindle. *G*, cell beginning to divide, chromosomes at poles of spindle. *H*, cell division complete. (Modified from *The Cell in Development and Heredity*, by E. B. Wilson.)

dyes are applied to the cell. It will be noted that the chromatin which at first (*A*) exists as granules in the nucleus, becomes in (*C*) definite bodies, the chromosomes. These chromosomes divide lengthwise (*E*) and the half chromosomes thus formed move to the poles of the spindles (*F*) and (*G*) so that when the cell divides each daughter cell has a longitudinal half of each chromosome. The

chromosomes in the daughter cells (*H*) are changed into granules so that the daughter cells are like the parent cell except in size. Chromosomes contain the *genes* or determiners, which are considered to be responsible for the inherited traits. Thus traits said to be inherited according to the Mendelian [6] laws are linked to the genes of the chromosomes.

Some cells are thought to divide directly. In direct division the cell elongates, the nucleus and cytoplasm become constricted in the center, and the cell divides and forms two cells which soon grow to the size of the original cell.

Differences in cells. — Cells differ in size, form, chemical composition, and function.

(1) As an example of variation in size [7] a voluntary muscle cell is about 25 mm. (1 in.) long and 0.05 mm. ($\frac{1}{500}$ in.) in diameter. The processes of a nerve cell may be 1 meter (39 in.) or more in length. A red blood cell has a diameter of 0.008 mm. ($\frac{1}{3200}$ in.).

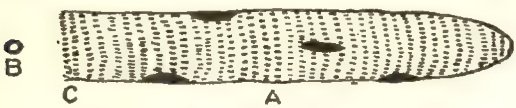


FIG. 10. — SIZES OF CELLS. *A*, voluntary muscle cell magnified in width 200 times and represented as cut off at *C*. At this magnification it would be about 200 inches long. *B*, red blood cell, also magnified about 200 times.

(2) The simplest form of cell is spherical, but this form is seldom realized except in unicellular plants and animals. In the human body the form of the cell is modified by the pressure of the surrounding structures, by the character and active movement of the cell substance, and by growth and differentiation.

(3) It is assumed that the marked difference in the appearance of cells is an expression of a chemical difference, which in turn is an evidence of difference in function.

(4) Each cell in a multicellular animal has a dual function: (*a*) to carry on the activities on which its own life depends, and (*b*) by specialization in some activity to assist in the special work of the tissue of which it forms a part.

The constituents of protoplasm. — Chemical analysis of protoplasm has shown that it always contains the following *chemical elements:*

[6] For information concerning Mendelian heredity refer to any of the books on heredity such as E. G. Conklin's *Heredity and Environment in the Development of Man.* Gregor Mendel (1822–1884), an Austrian monk, was the first to demonstrate experimentally the laws of inheritance.

[7] On page 592 will be found accurate ratios between the metric system and the system of lengths, weights, and measures used in the United States.

Carbon	(C)	Form 96.25 per cent of total weight of body	18.0%
Hydrogen	(H)		10.
Oxygen	(O)		65.
Nitrogen	(N)		3.0
Sulphur	(S)		0.25
Phosphorus	(P)		1.0
Chlorine	(Cl)		0.15
Sodium	(Na)		0.15
Potassium	(K)		0.35
Calcium	(Ca)		1.5
Magnesium	(Mg)		0.05
Iodine	(I)		0.00004
Iron	(Fe)		0.004%
Silicon	(Si)	Very minute amounts	
Fluorine	(F)		
Perhaps other elements	traces		

In the human body free oxygen, hydrogen, and nitrogen have been found in the blood and intestines, but the bulk of these elements as well as all of the others exist in the form of complex compounds in the cells. The compounds are divided into two classes, *i.e.*, organic and inorganic. Those which contain carbon are organic, and those which do not are inorganic.

The *organic compounds* found in cells are proteins, carbohydrates, and fats. They contain the same elements as the similarly named organic compounds of our food, *i.e.*, proteins of the human cells contain the same elements as the proteins of our food, etc. But it must not be understood that because of this they are exactly the same. Animal protein and human protein have distinctive characteristics, just as beef and mutton have distinctive characteristics. All three contain the same essential elements, but in different absolute quantities, relative quantities, and combinations. These variations and the presence or absence of additional elements result in marked differences in physical and chemical characteristics. The same holds true of carbohydrates and fats. The essential elements in proteins are carbon, hydrogen, oxygen, and nitrogen, probably also, sulphur and phosphorus; in carbohydrates and fats the essential elements are carbon, hydrogen, and oxygen. All organic compounds taken into the human body are split up into simple substances, *i.e.*, carbohydrates into simple sugars; fats into glycerin and fatty acids; proteins into amino-acids. All of these simple substances are carried by the blood and lymph to the cells, and the cells are able to build them up into carbohydrates, fats, and proteins that are distinctly human. These may then be stored in the cells, or utilized for growth or the production of energy, as indicated in Fig. 8. A more complete discussion will be found in Chapters XIX and XX.

The remaining elements exist in cells partly as dissolved mineral salts and partly in combination with the organic compounds. The mineral elements remain either wholly or largely in the ash of food materials when the latter are burned in the air, hence they are grouped as *ash constituents.*

Only small amounts of these elements are needed but they are essential parts of the cells and must be provided in the food in order to maintain health.

Water is one of the most essential needs of cells and constitutes over two-thirds of the body weight, hence the physiological need of water.

SUMMARY

System. — An arrangement of organs, closely allied and concerned with the same function.

Nine systems are found in the human body:

Skeletal.	System of internal secretions.
Muscular.	Respiratory.
Nervous.	Digestive.
Vascular, or circulatory.	Excretory.

Reproductive.

Organ. — A physiological unit composed of two or more tissues associated in performing some special function.

Tissue. — A group of cells with more or less intercellular material.

Cell. — The structural and physiological unit of the body.

Ameba. — An example of a unicellular animal which lives because it is able to carry on the biological activities of support, breathing, digesting, collecting and distributing, moving, excreting, irritability, and reproducing.

Comparable activities
- Biological activities of ameba.
- Functions of the nine systems in human body.
- Life activities of cells.

Cell
- Protoplasm
  - Cytoplasm
    - Central bodies.
    - Golgi bodies.
    - Plastids.
    - Chondriosomes.
    - Vacuoles.
  - Nucleus
    - Plasmosome or true nucleolus.
    - Chromatin (basichromatin).
    - Linin (acidichromatin).
    - Karyosome or chromatin nucleolus.
- Metaplastic or paraplastic bodies
  - Foods.
  - Wastes.
  - Other storage products.

- **Metabolism**
  - **Metabolism** — life activities of cells
    - Anabolism — building-up process.
    - Catabolism — breaking-down process.
  - 1. Support
  - 2. Respiration
    - Provides oxygen for oxidation.
    - Liberates heat.
    - Excess carbon dioxide removed.
  - 3. Use of foods
    - Convert nonliving foods into protoplasm.
    - Foods may also be oxidized to yield energy and regulate body processes.
  - 4. Motion
    - (*a*) Ameboid movement.
    - (*b*) Ciliary movement.
  - 5. Circulation — Streaming of the protoplasm, within the limits of the cell.
  - 6. Excretion — Discharge of waste substances.
  - 7. Irritability — Ability to respond to stimuli and to *conduct* the stimuli throughout the cell.
  - 8. Cell division
    - (*a*) Indirect division or mitosis.
    - (*b*) Direct division or amitosis.

- **Differences in cells**
  - Size
    - Voluntary muscle cell may be 25 mm. long.
    - Processes of nerve cells may be a meter or more.
    - Red blood cell 0.008 mm. in diameter (average).
  - Form depends on
    - Pressure.
    - Character of cell contents.
    - Movements of cell.
    - Growth and differentiation.
  - Chemical composition — related to special work of cell.
  - Function
    - 1. To carry on activities on which its own life depends.
    - 2. To assist in special work of tissue of which it forms a part.

- **Bulk of chemical elements found in body exist in form of compounds**
  - Organic compounds — contain carbon
    - Carbohydrates.
    - Fats.
    - Proteins.
  - Inorganic compounds — contain no carbon.

- **Proteins contain**
  - Carbon.
  - Hydrogen.
  - Oxygen.
  - Nitrogen.
  - Sulphur, Phosphorus } sometimes.

- **Carbohydrates contain**
  - Carbon.
  - Hydrogen.
  - Oxygen.

- **Water contains**
  - Hydrogen.
  - Oxygen.

- **Fats contain**
  - Carbon.
  - Hydrogen.
  - Oxygen.

- **Ash constituents**
  - Sulphur.
  - Phosphorus.
  - Chlorine.
  - Sodium.
  - Potassium.
  - Calcium.
  - Magnesium.
  - Iodine.
  - Iron.
  - Silicon.
  - Perhaps other elements.

CHAPTER III

DEVELOPMENT OF EMBRYO; TISSUE DIFFERENTIATION

The human organism begins life as a single-celled embryo, derived from the fusion of preëxisting parental cells, — the ovum and the spermatozoön. This one-celled embryo undergoes repeated mitotic cell division, making the multicellular organism. During life, cell division continues throughout the body, growth and repair of the complex organism being accomplished by cell division, the differentiation of cells and the accumulation of more or less material between the cells. The purpose of this chapter is to present some of the phases of this development.

The life cycle of man may be divided into the two periods of *prenatal life* and *postnatal life.* Prenatal life is generally divided into the following:

- Period of the ovum — first two weeks of development.
- Embryonic period — from the beginning of the third week to the end of the second month.
- Fetal period — from the beginning of the third month to the time of birth.

Postnatal life may be divided into these periods:

- Neonatal period — extending from birth to end of second week.
- Infancy — from the second week to the end of the first year.
- Childhood — from the end of infancy to puberty, which comes at about the twelfth to the sixteenth year.
- Adolescence — extending from puberty into the second decade or beginning of the third.
- Maturity — lasting until the end of the reproductive period, or later. This is followed by the period of old age.

Germinal tissues. — In very early embryonic life the tissues which will develop into the reproductive glands, called the *germinal tissues* of the body, can be distinguished from the tissues which will form the other parts of the body, called the *somatic tissues.* An embryo of about six weeks shows the germinal tissues as a pair of genital folds in the dorsal region of the embryo, and by about the tenth or eleventh week these are differentiated into the reproductive

organs, called *gonads*. The female gonads are called *ovaries*, the male gonads are called *testes*. During fetal life and infancy, these organs remain relatively inactive, undergoing cell division at somewhat the same rate as the other parts of the body, but producing no functional *germ cells*, or *gametes*. At puberty the ovaries and testes (singular, *testis*) begin more rapid development in all parts, and functional germ cells (ova and spermatozoa) are produced.

Germ cells. — Egg cells or ova are thought to be derived from the germinal epithelium of the ovary. Each *ovum* comes to be sur-

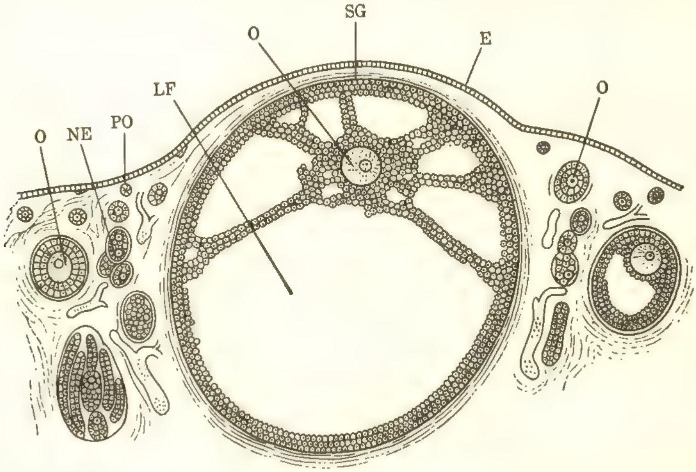


FIG. 11. — DIAGRAM. Thin section of a portion of an adult mammalian ovary. It shows a fully formed vesicular (ovarian, Graafian) follicle and others in various stages of development.

E, epithelial cells investing the ovary; *LF*, cavity of follicle containing follicular fluid or *liquor folliculi*; *NE*, nests of epithelial cells; *O*, *ovum*; *PO*, primitive ovum; *SG*, stratum granulosum or outer layer of cells of the follicle. The ovum of the mature follicle is located near the side of the follicle and is surrounded by several layers of cells forming the *cumulus oöphorus*. The mature follicle is surrounded by a sheath, the *theca folliculi*. The diagram also shows a few of the blood vessels which with connective tissue compose the stroma of the ovary.

rounded by a cellular layer, which gradually enlarges to form the *Graafian* follicle.[1] (See Fig. 11.) Each follicle, when fully developed, forms a marked protuberance on the surface of the ovary, and ruptures, liberating the contained ovum to the exterior of the ovary. This discharge of ova from the ovary is termed *ovulation;* and it is thought that, in general, ovulation takes place about midway between two menstrual periods, the ovaries possibly alternating each month in the liberation of a single ovum. The ovum

[1] Rheinhart de Graaf, Dutch anatomist, 1641–1673.

is globular, about 0.2 mm. ($\frac{1}{125}$ in.) in diameter. The fully grown Graafian follicle is about 10 mm. ($\frac{2}{5}$ in.) in diameter. *Spermatozoa* (sperm cells) are derived by cell division from the epithelial cells which line the tubules of the testes. When fully formed, a spermatozoön is about 0.05 mm. ($\frac{1}{500}$ in.) in length, and is shaped much like a tadpole. It consists of an elliptical head, about 0.003 mm. long, a rod-shaped middle piece of about the same length, and a tail, which gradually tapers. The head contains the nuclear material of the cell and hence the chromatin, the middle piece contains the centrioles. When activated by the fluid constituents of the *semen*, the spermatozoa swim actively by means of a lashing motion of the tail.

Maturation of the germ cells. — *Maturation* is the process by means of which the ovum and the spermatozoön are prepared for fertilization. During the process of formation of functional ova from the germinal epithelium of the ovary, the number of chromosomes in each ovum is reduced to one-half the original number. Human cells have 48 chromosomes (23 pairs of *ordinary chromosomes* and a pair of *sex chromosomes*, usually designated as a pair of x chromosomes). Each mature ovum has one member of each pair of chromosomes (23 chromosomes and an x chromosome). The details of the maturation of ova and spermatozoa are given in Fig. 12. In human individuals, it is thought that the cell divisions resulting in the reduction of the number of chromosomes are begun before ovulation, one polar body being produced, but that reduction is not completed by the formation of the second polar body until after fertilization has taken place. Human spermatozoa have 24 chromosomes, one member of each pair of chromosomes. Maturation of spermatozoa takes place before they are detached from the walls of the seminiferous tubules.

According to most authorities,[2] the cells of male individuals have 48 chromosomes (23 pairs of ordinary chromosomes and one pair of sex chromosomes, usually called x and y). Half of the spermatozoa have 23 chromosomes and an x chromosome, and half of them have 23 chromosomes and a y chromosome, 24 chromosomes in all, in each spermatozoön. If an ovum is fertilized by a spermatozoön with an x chromosome, it will then have 23 pairs of ordinary chromosomes and a pair of x chromosomes, and will, therefore, produce a female individual. If an ovum is fertilized by a spermatozoön having a y chromosome, it will then have 23 pairs of ordinary chromosomes and a pair made up of an x and a y chromosome, and will produce a male individual. Since ova are all alike in the possession of an x chromosome, and since there are equal numbers of the two kinds of spermatozoa, there should be an equal

[2] T. S. Painter and others.

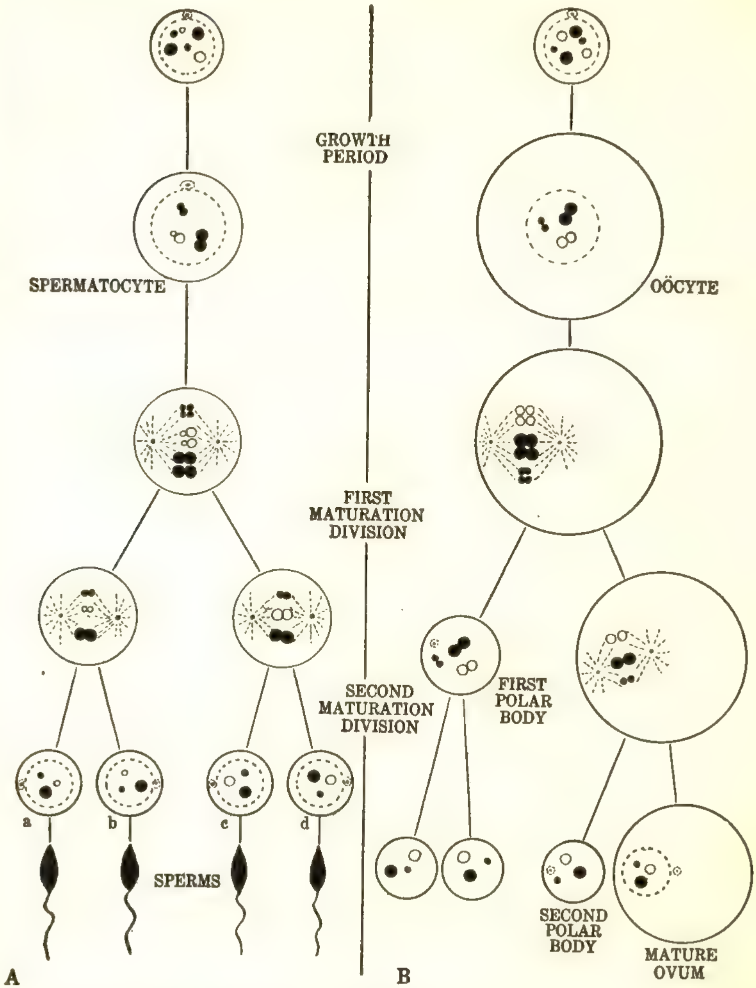


FIG. 12. — DIAGRAM TO SHOW MATURATION. This process is also called *meiosis*. *A*, sperm cells. *B*, ova. Note in both, a growth period followed by two maturation divisions yielding four cells. In *A* each of these four cells is a functional sperm. In *B* only one of the cells is a functional ovum, the other three usually disappear. The spermatocyte and oöcyte are shown with two pairs of autosomes (black) and one pair of sex chromosomes (white), making six chromosomes in each. In the oöcyte the two sex chromosomes are alike (white circles of same size). These are the two x chromosomes referred to in the text. It is evident that in *B* all possible ova will be alike in having one x chromosome. In the spermatocyte the two sex chromosomes are not alike (a large white circle and a small white circle). These are the x and y chromosomes referred to. There are in *A*, therefore, two possible kinds of sperm cells — (c) and (d) containing an x chromosome and (a) and (b) containing a y chromosome. (Modified from *Essentials of Human Embryology*, G. S. Dodds. Courtesy of John Wiley & Sons.)

number of male and female individuals produced, due to inheritance of sex through the chromosomes, as explained above.[3]

Fertilization. — This term is applied to the penetration or impregnation of the ovum by the spermatozoön, and the *fusion of their nuclei.* It is thought to take place in the upper portion of the uterine tube, probably within a few hours of ovulation and of

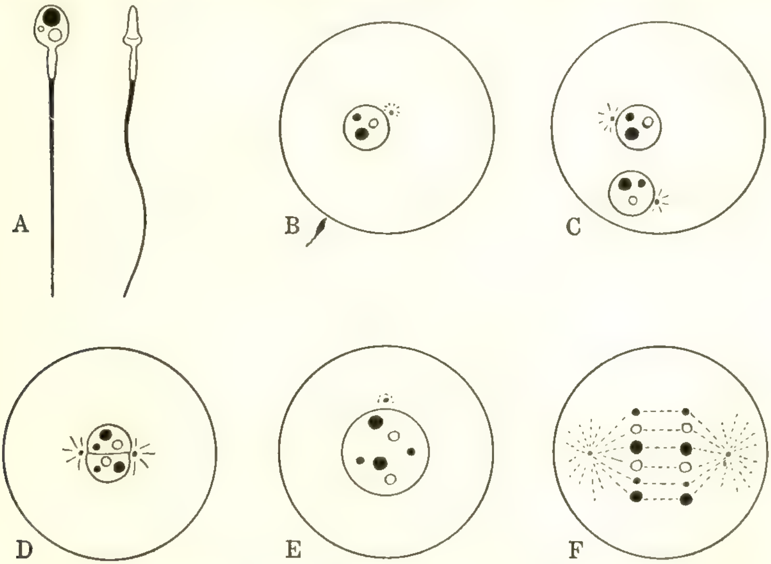


FIG. 13. — DIAGRAM TO SHOW FERTILIZATION. *A*, human sperm cell, face and side views. Note the head containing the chromosomes, the middle piece and the tail. *B*, sperm entering ovum. *C*, sperm nucleus within ovum, showing chromosomes. *D*, the sperm nucleus approaches the ovum nucleus. *E*, the two nuclei fuse and fertilization is complete, the zygote formed in *E* has six chromosomes — two pairs of autosomes (black) and one pair of sex chromosomes (white). Since the two sex chromosomes are alike (x chromosomes) the zygote would develop into a female. *F*, first embryonic cell-division which when complete would give a two-celled embryo. (Modified from *Essentials of Human Embryology*, G. S. Dodds.)

insemination or semination. During this time the ovum moves down into the tube from the ovary, and the spermatozoa move up through the uterus and tube. As soon as the head of the spermatozoön enters the ovum, the tail disappears and the head takes on the appearance of a nucleus. The nucleus of the ovum and the nucleus of the spermatozoön approach each other and fuse more or less completely into a single nucleus known as the *cleavage*

[3] For studies of selection of sperm cells, environmental factors, etc., see Biological Journals. *Developmental Anatomy*, L. B. Arey, 1930 edition, has a good bibliography.

nucleus. The cell thus resulting is a one-celled embryo (*zygote*) and contains the full number of chromosomes, 48, or 24 pairs, one member of each pair being derived from the ovum and one member from the spermatozoön, as shown in Fig. 13. The chromosomes contain *genes.* A gene is that portion of chromatin that is responsible for an inheritance trait. One-half the *genes,* or inheritance determiners, which are in the chromosomes, are, therefore, derived from each parent, the germ cells forming the continuity link between succeeding generations.

Heredity. — This term is applied to the transmission of the potential characteristics of parents to their children. The mechanism of transmission is thought to be the maturation of the germ cells and fertilization, as described. It is evident that it is potentialities, rather than characteristics, that are transmitted. In different environments, during the growth of the individual and the development of the potentialities into characteristics, these developed characteristics may be modified to a greater or less extent. It is believed that the offspring receives one member of each pair of chromosomes from each parent. The genes of these chromosomes are similar; for instance, each of the paired chromosomes may carry a "gene for eye color," or for hair form, or for short fingers, etc. These genes may be the same or alternative in effect: for instance, in a given case (A), the offspring may receive a "gene for brown eyes" from each parent, in the paired chromosomes; or, in another case (B), the offspring may receive a "gene for brown eyes" from one parent and a "gene for blue eyes" from the other parent, in the paired chromosomes; or, in some other case (C), a "gene for blue eyes" from each parent.[4] Some traits seem to be dominant under usual conditions, so that if the genes are present, the traits are bound to appear. Some traits are recessive, and do not appear, if the genes for the dominant traits are present. For instance, in (A), the individual will have brown eyes; in (B), since brown is dominant to blue, the offspring will have brown eyes, although the alternative "blue gene" is present; in (C), the eyes will be blue, there being no "gene for brown eyes" present. Dominance may be complete, partial, or absent; it is, also, a relative term. A gene which is dominant to a certain gene may be recessive to some other gene. Genes for recessive traits may be carried through generations, along with genes for dominant traits, the recessive traits

[4] Actually, the inheritance of these characteristics is probably much more complex.

only appearing as characteristics in individuals lacking the dominant genes.[5]

Cleavage and the formation of germ layers. — Fig. 14 shows stages of development described here. One of the results of fertilization is the activation of the fertilized ovum, so that it begins to undergo cell division. It divides and subdivides, until an enormous number of cells called *blastomeres* is formed; typically, the single cell becomes two, then four, then eight, etc., though this uniform rate is not maintained, some of the blastomeres developing

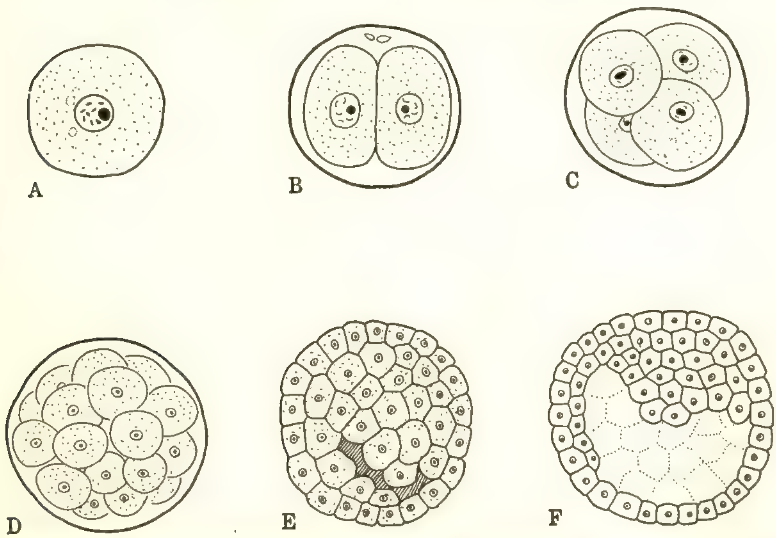


Fig. 14. — Diagram to Show Very Early Stages of Mammalian Development. *A*, one-celled embryo; *B*, two-celled embryo; *C*, four-celled embryo; *D*, berry-like ball of cells or *morula; E*, beginning the formation of the *blastocyst; F*, well-developed blastocyst, consisting of a hollow ball of *trophoblast* cells and an inner mass of cells known as *blastomeres*.

more rapidly than others. The first few blastomeres form a mulberry-shaped group of cells called the *morula*. As the blastomeres increase in number, they come to form a hollow, fluid-filled ball of cells, with a disc of cells near its periphery. This is a modified blastula, and is known as the *blastocyst*, or blastodermic vesicle. The cells of the disc (blastoderm) develop into the embryo, while the outer cells later assist in the formation of the fetal membranes. The cells in the blastoderm increase in number and come to be

[5] For description of experiments in genetics and their cytological interpretation, see books on heredity, such as E. G. Conklin's *Heredity and Environment in the Development of Man;* A. F. Shull's *Heredity;* and H. E. Walter's *Genetics*, and others.

arranged in two layers, an outer layer of cells called the *ectoderm*, and an inner layer called the *entoderm*.[6] This embryo composed of two cell-layers is called the *gastrula*. Between the ectoderm and entoderm the *mesoderm* is formed. The mesoderm separates into two layers, the somatic or parietal layer, lying next to the ectoderm, and the splanchnic layer, lying next to the entoderm. These three

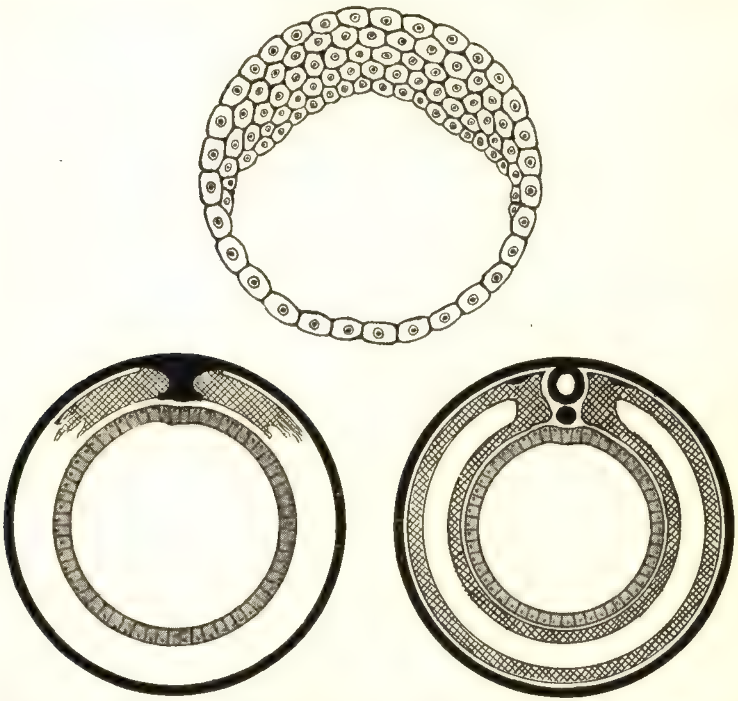


FIG. 15. — DIAGRAM OF A SECTION OF AN EMBRYO SHOWING THE BEGINNING OF TISSUE FORMATION. The embryonic disc shows the cells arranged in layers. Two diagrams of sections of embryos showing later stages of tissue formation. *Ectoderm* is shown in black, *endoderm* as cells and the two layers of *mesoderm* are cross-hatched. At the right the space between the layers of mesoderm is the future body cavity. The neural tube and the notochord are shown.

layers of cells are called *germ layers*, and also *embryonic* or *primary tissues*.[7] The ectoderm and the somatic mesoderm form the *somatopleure* and from this the body-wall is developed. The entoderm and the splanchnic mesoderm form the *splanchnopleure* and from this the viscera are developed. Between the two layers of mesoderm is a cavity, the *cœlom*, which develops into the body

[6] Also spelled endoderm.
[7] *Vertebrate Embryology*, W. Shumway.

cavity, and which later becomes divided into the peritoneal cavity, the pleural cavity, and the pericardial cavity. Development of the germ layers into the differentiated tissues is called *histogenesis*. In this way, the general plan of vertebrate structure, that is, a tubular body-wall enclosing a cavity in which lie the more or less tubular viscera, comes to be formed.

Histogenesis. — The tissues derived from these germ layers are as follows:

Ectoderm	Epidermis and its appendages. Epithelium of the beginning of gastropulmonary tract (nose, mouth) and the termination (anus). Tissues of the nervous system.
Mesoderm	The connective and supporting tissues. The muscular tissues. Tissues of the vascular and lymphatic systems, including endothelium and circulating cells. Endothelium lines closed cavities of body. Epithelium of a part of the genito-urinary system.
Entoderm	Epithelium of the gastropulmonary tract, except those portions of ectodermic origin at the beginning (mouth, nose) and the termination (anus).

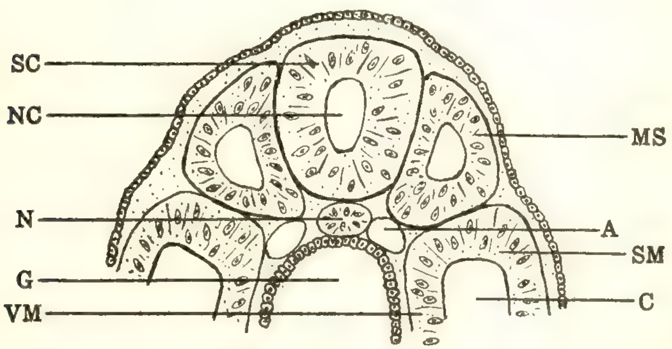


FIG. 16. — DIAGRAM OF A PORTION OF A CROSS SECTION OF A HUMAN EMBRYO OF ABOUT TWO WEEKS OF AGE. *A*, aorta; *C*, cœlom; *G*, mid-gut; *MS*, myotome or mesoblastic somite; *N*, notochord; *NC*, central canal of neural tube; *SC*, wall of neural tube; *SM*, somatic mesoderm; *VM*, splanchnic mesoderm.

From the layers of the mesoderm in its early history, the *mesenchyme* is formed. This is a network of irregular cells, loosely joined together. The spaces in this network contain a fluid. From the mesenchyme the supporting and circulatory tissues of the body are gradually developed. The ectoderm and entoderm probably contribute to the formation of the mesenchyme.

Organ Formation. — As the tissues are gradually differentiated, they become grouped into organs, mainly by unequal rates of growth and the production of pockets or folds, or, in other words, by invagination or evagination. This process is called *organogenesis.* As the embryo grows, the embryonic organs increase in size, become differentiated locally in various ways, and organized into systems of organs. This association of the systems working harmoniously together produces the organism. The primitive alimentary canal is folded into tubular form from the splanchnopleure, and the pancreas, liver, and respiratory system develop as pockets growing out from this tube. They are lined with entoderm, therefore. The *neural tube* is infolded from the ectoderm, and gives rise to the brain, the spinal cord, and nerves. The *notochord,* or embryonic backbone, a rod of cells, develops between the alimentary tube and the neural tube, and later becomes replaced by the segmented vertebral column. Blood vessels develop in the mesenchyme as a network of channels lined with endothelium, which later differentiate into the blood and lymph vascular systems. The urogenital system develops from the intermediate mass of mesoderm, in the dorsal region of the body.

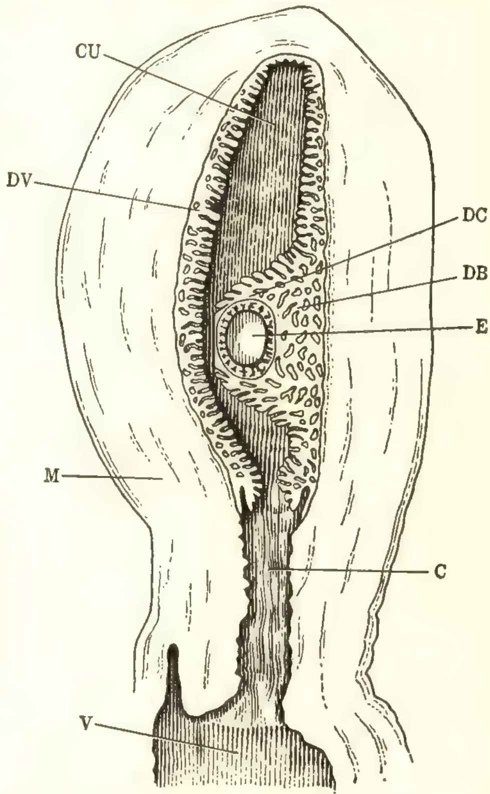


FIG. 17. — DIAGRAM OF A LONGITUDINAL SECTION OF THE GRAVID UTERUS SHOWING THE RELATIONS OF THE IMPLANTED EMBRYO AND THE UTERINE MUCOSA. *C*, cervix of uterus; *CU*, cavity of uterus; *DB*, decidua basalis; *DC*, decidua capsularis; *DV*, decidua vera; *E*, embryo of about two weeks of age; *M*, muscle layers of wall of uterus; *V*, vagina.

Implantation. — During the early stages of the cleavage period,

the embryo is descending through the uterine tube into the uterus. At about the eighth or tenth day after fertilization, it becomes embedded or implanted in the uterine mucosa, which grows over it. Certain membranes, (1) maternal and (2) fetal, are formed for the protection and nourishment of the developing fetus.

(1) **Maternal or decidual membranes.** — The mucosa or lining membrane of the uterus becomes differentiated into the *decidua basalis,* against which the embryo rests, and which forms the maternal part of the placenta, the *decidua capsularis,* which grows over the embryo, and the *decidua vera* (or *parietalis*), the remainder of the uterine mucosa (Fig. 17). The decidual membranes, together with the fetal membranes, are discarded soon after the extrusion of the child from the uterus, as the *after-birth.*

(2) **Fetal membranes.** — These are the *chorion,* the *amnion,* the *yolk sac,* and the *allantois.* The *yolk sac* and *allantois* are pocket-like extensions of the ventral side of the embryo, and are to be seen in the umbilical cord of a *young* embryo [8] (Fig. 18). The *amnion* is a thin, transparent sac filled with fluid, which surrounds the embryo, keeping it moist, acting as a pressure buffer, and equalizing the varying pressures around it. The *chorion* is developed from the outer layer of the blastocyst, together with a layer of mesoderm, and surrounds the embryo. It develops villi, which erode the mucosa of the uterus, forming pits into which they grow. The villi extending into the decidua basalis become numerous, long, and highly branched. This portion of the chorion is called *chorion frondosum,* and becomes the fetal part of the placenta. The villi on the other portions of the chorion do not continue to grow with the embryo, and may even disappear, leaving this surface of the chorion smooth (*chorion læve*). Through the *umbilical cord,* which attaches the fetus [9] to the placenta, two umbilical arteries carry fetal blood from the fetus to the capillaries of the fetal placenta, and the umbilical vein returns this blood to the fetus.

Placenta. — The placenta is composed of an embryonic portion (*chorion frondosum*) and a maternal portion (*decidua basalis*). Each has its own circulation, and there is no connection between the fetal and maternal circulations. Exchange of materials takes

[8] The yolk sac and allantois, though serving in a certain sense as fetal membranes in some species, can scarcely be called fetal membranes in man.

[9] The term *embryo* is applied to the organism during the first two months of development. During the third month, the embryo begins to take on human appearance, and is called a *fetus.*

place by diffusion and absorption. Food and oxygen in solution in the mother's blood diffuse through the tissues of the villi into the fetal blood; waste materials diffuse from the fetal blood through the tissues of the villi into the maternal blood.

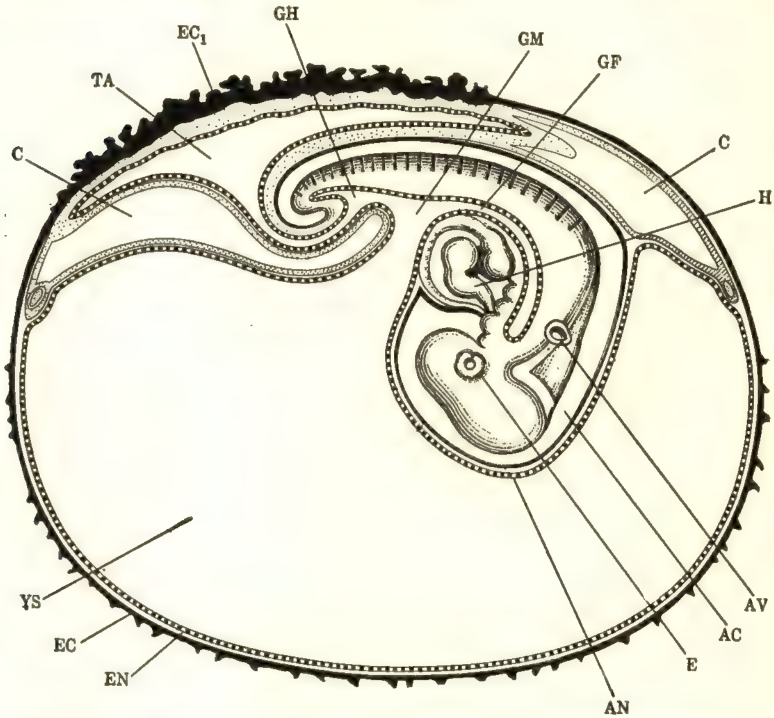


FIG. 18. — DIAGRAM OF A MAMMALIAN EMBRYO (RABBIT) SURROUNDED BY THE EMBRYONIC MEMBRANES. *AC*, amniotic cavity containing amniotic fluid; *AN*, amnion; *AV*, auditory vesicle; *C*, extra-embryonic cœlom; *E*, eye; *EC*, ectoderm; EC_1, thickened ectoderm giving rise to part of embryonic placenta; *EN*, endoderm; *GF*, fore-gut; *GH*, hind-gut; *GM*, mid-gut; *H*, heart; *TA*, cavity of allantois; *YS*, yolk-sac.

In many animals the allantois comes into extensive contact with the placental area of the ectoderm bringing the allantoic blood-vessels into close contact, in the embryonic placenta, with the uterine wall. In man the allantois is rudimentary and is to be seen only in the umbilical cord of a very young embryo.

It has been estimated that the total area of villi through which this diffusion of substances in solution can take place is about 6.5 square meters.[10]

Early embryos. — Figs. 20 and 21 show human embryos of different ages. It will be noted that development takes place most rapidly in the head region, and with increasing slowness toward the

[10] G. S. Dodds, *The Essentials of Human Embryology.*

caudal end of the embryo, more rapidly also in the dorsal than in the ventral region. The embryo, at first a disc of cells by differential growth, which results in folding, comes to have a roughly cylindrical form attached to the embryonic membranes by the body stalk

Fig. 19. — Diagram of a Section of Uterus with Fetus. The amnion is represented by a thin black line bounding the amniotic fluid in which the fetus lies. The heavy black line is the chorion. The umbilical cord shows two arteries twisted around the single vein. The fetal placenta shows at left. *Developmental Anatomy*, L. B. Arey.

Among the earliest visible external structures are the *primitive groove*, an important area of rapid cell division and tissue differentiation lasting for a short time only; the *neural groove*, which by growth and infolding becomes the *neural tube*, from which the brain and spinal cord are developed; and the *somites*, paired masses of mesodermal tissue, showing through the ectoderm. The somites

develop into the vertebræ, and the ribs, muscles, and connective tissues organized with them. For the development of other external features, reference must be made to textbooks on embryology. Chapter XXIV discusses the anatomy and physiology of the reproductive organs.

SUMMARY

The new organism arises by fusion of parental cells, — ova and spermatozoa. Growth is accomplished by the multiplication of cells, differentiation of cells, and accumulation of material between them.

Germinal Tissue
- *Somatic tissues* — all tissues except reproductive tissues.
- *Germinal tissues*
  - *Ovaries* — produce ova.
  - *Testes* — produce spermatozoa.

Germ Cells or Gametes
- *Ova* or *egg-cells*, $\frac{1}{125}$ in. in diameter. Surrounded by Graafian follicles.
- *Ovulation* — Rupture of Graafian follicles and discharge of ova from ovary. Probably occurs about midway between menstrual periods.
- *Spermatozoa*, $\frac{1}{500}$ in. long. Consist of head, middle-piece, and tail. Head is nucleus.

Maturation of Germ Cells
- Human cells have 48 chromosomes (or 24 pairs).
- During maturation the number of chromosomes in the germ cells is reduced to one-half that number.
- Each mature ovum or spermatozoön has, therefore, 24 chromosomes — one member of each of the 24 pairs.
- Maturation of ova probably not complete until after fertilization.
- Maturation of spermatozoa complete before they are detached from the walls of the seminiferous tubules.

Fertilization
- Term applied to penetration of ovum by spermatozoön and fusion of their nuclei.
- Restores original number of chromosomes — 48. One-half the chromosomes contributed by each germ cell.
- Activates the ovum. Cell division begins.

Heredity
- Transmission of potential characteristics from parents to children.
- One member of each pair of chromosomes from each parent.
- Paired chromosomes contain genes for similar, or alternative traits, *e.g.*, each of the members of a pair of chromosomes may contain a " gene for blue eyes " or one member of a pair may contain a " gene for blue eyes " and the other member a " gene for brown eyes."
- Dominance may be complete, partial, or absent.
- Genes for recessive characteristics may be carried through generations, developing into characteristics only when the dominant genes are not present.

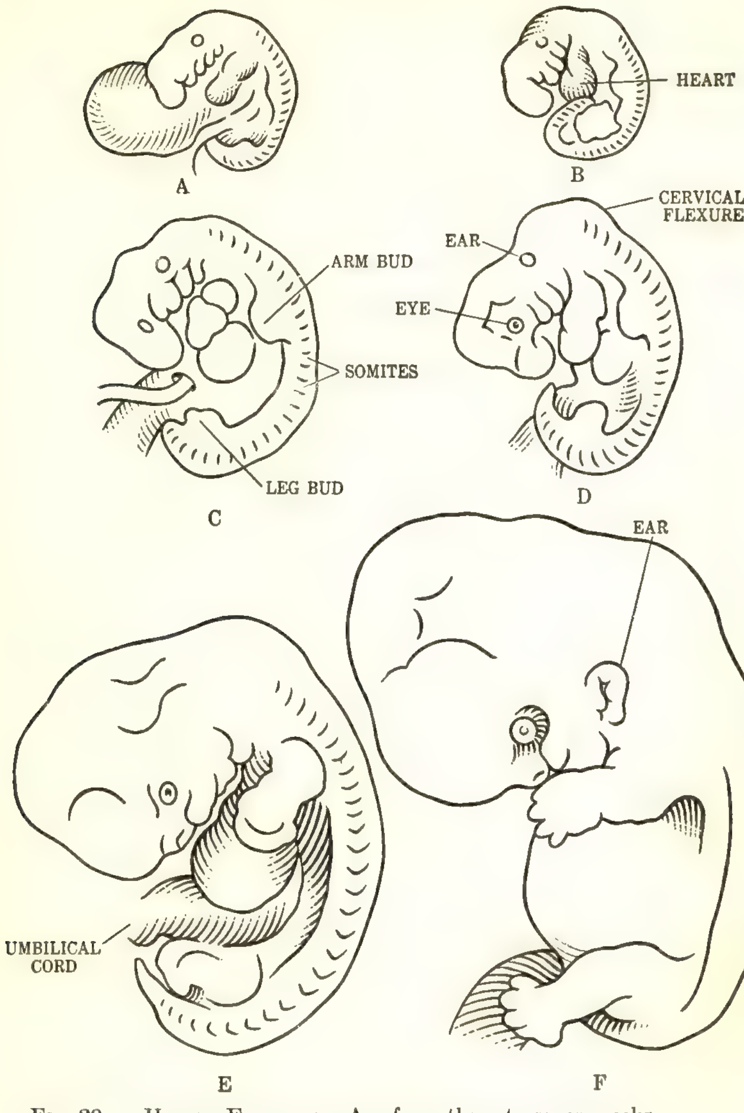


FIG. 20. — HUMAN EMBRYOS. Age from three to seven weeks.

FIG. 21. — HUMAN EMBRYO ABOUT 25 MM. LONG, AGE ABOUT TWO MONTHS. Human form established, fetal period of development begun. Cervical flexure nearly gone; head, though still relatively large, lifted; body straightened. Neck well marked though short. Face developing; eyelids, nose, lips, external ears, cheeks appear. Ventral body-wall well formed, prominence due to the heart less conspicuous. Fore limbs have appearance of arms, thumbs well marked off from fingers, shoulders begin to appear. Legs smaller than arms, soles of feet close together.

Development of Embryo

- **Cleavage and Formation of Germ Layers**
  - *Fertilization* activates the ovum — cell multiplication begun.
  - *Morula* — a group of cells resulting from cell multiplication.
  - *Blastocyst,* or modified blastula — a hollow ball of cells, with disc of cells near the periphery at one point — the *blastoderm.*
  - *Gastrula* — an embryo of two layers, ectoderm and entoderm. *Ectoderm* is the outer layer of blastoderm; *entoderm* is the inner layer of blastoderm.
  - *Mesoderm* develops between ectoderm and entoderm. Somatic layer of mesoderm and the ectoderm give rise to the body wall (*somatopleure*). Splanchnic layer and entoderm give rise to viscera (*splanchnopleure*).
  - *Cœlom* — the cavity between the layers of mesoderm becomes divided into the peritoneal, pleural, and the pericardial cavities.
- **Tissue Formation**
  - **Ectoderm**
    - Epidermis and its appendages.
    - Epithelium of the beginning of gastropulmonary tract (nose, mouth) and the termination (anus).
    - Tissues of the nervous system.
  - **Mesoderm**
    - The connective and supporting tissues.
    - The muscular tissues.
    - Tissues of the vascular and lymphatic systems, including endothelium and circulating cells. Endothelium lines closed cavities of body.
    - Epithelium of a part of the genito-urinary system.
  - **Entoderm**
    - Epithelium of the gastropulmonary tract, except those portions of ectodermic origin at the beginning (mouth, nose) and at the termination (anus).
  - **Mesenchyme**
    - Loosely arranged network of cells derived from the layers of the mesoderm in the dorsal region where the tissue is not completely separated into layers.
    - Develops into supporting and circulatory tissue.

Development of Embryo

- **Organ Formation**
  - Tissues become pocketed or folded by unequal rates of growth, forming organs.
  - Embryonic organs grow and become differentiated into systems.
  - Association of systems produces organism.
  - Primitive alimentary canal formed from entoderm. Pancreas, liver, and respiratory organs develop as pockets growing out from it.
  - Neural tube developed from ectoderm. Gives rise to brain, spinal cord, and nerves.
  - *Notochord*, or embryonic backbone, a rod of cells between neural tube and alimentary canal. It is later replaced by segmented vertebral column.
  - Blood and lymph vascular systems develop from mesenchyme.

Implantation

- Embryo embedded in uterine mucosa about eight to ten days after fertilization.
- **Maternal or Decidual Membranes**
  - *Decidua basalis* — uterine mucosa, in which embryo lies. It forms the maternal portion of the placenta.
  - *Decidua capsularis* — uterine mucosa grown over the embryo.
  - *Decidua vera* — the other portions of the uterine mucosa.
  - Deciduæ discarded with fetal membranes after birth of child, as the *after-birth.*
- **Fetal Membranes**
  - *Yolk sac* and *allantois* are pocket-like extensions of the ventral side of the embryo. They are to be seen in the umbilical cord of a *young* embryo.
  - *Amnion* — a thin, fluid-filled sac surrounds the embryo.
  - *Chorion* — developed from the outer layer of blastocyst and mesoderm. It forms villi which grow into *decidua basalis. Chorion frondosum* is that portion with numerous, long, much-branched villi. It forms the fetal portion of the placenta. *Chorion læve* is the other portion of the chorion.
- **Placenta**
  - *Chorion frondosum,* the fetal portion. *Decidua basalis,* the maternal portion.
  - There is no connection between fetal and maternal blood. Exchange of materials is by diffusion and absorption. Food and oxygen diffuse through tissues of villi from maternal blood into fetal blood. Wastes diffuse through tissues of villi from fetal to maternal blood.
  - *Umbilical cord* attaches fetus to placenta. It contains two umbilical arteries and an umbilical vein.

Development of Form

- Embryos develop more rapidly at head end and with increasing slowness toward caudal end — more rapidly in dorsal than in ventral region.
- **External Structures of Young Embryos**
  - *Primitive groove* — area of rapid cell multiplication and differentiation lasts for a short time only.
  - *Neural groove* — becomes neural tube and develops into brain, spinal cord, and nerves.
  - *Somites* — paired masses of mesoderm, which develop into vertebræ and the ribs, muscles, and connective tissues organized with them.

CHAPTER IV

CONNECTIVE TISSUES

The tissues of which the body is formed are found to be comparatively few in number, and some of these, although at first sight apparently distinct, have so much in common in their structure and origin, that the number becomes still further reduced, until we can distinguish only four distinct tissues, *viz.:*

1. The connective tissues.
2. The muscular tissues.
3. The nerve tissues.
4. The epithelial tissues.

Connective tissues. — These tissues differ in appearance but are alike (1) in that the cellular element is at a minimum and the intercellular material is abundant; (2) with one exception, neuroglia, they develop from the mesoderm; (3) they serve to connect and support the other tissues of the body; (4) they originate no action but are acted upon by the other tissues; and (5) with few exceptions they are highly vascular. The intercellular substance determines the physical characteristics of the tissue. The connective tissues may be classified as follows:

1. **Embryonal** tissue.
2. **Areolar** tissue.
3. **Adipose** tissue.
4. **Liquid** tissues.
5. **Reticular** tissue.
6. **Elastic** tissue.
7. **Fibrous** tissue.
8. **Neuroglia.**
9. **Cartilage.**
10. **Bone** or **osseous** tissue.

1. Embryonal tissue. — In the development of connective tissue from the mesoderm, the cells unite to form a network with closely-packed nuclei. The cytoplasm increases more rapidly than the nuclei with a resulting differentiation into cells and a primitive semi-fluid intercellular ground substance. This tissue is known as embryonal tissue and is widely distributed throughout the embryo. It represents a stage in the development of connective tissue. Normally it does not occur in the adult, but is the type found in connective tissue repair after injuries and in certain pathological growths. Embryonal tissue, in which the ground substance is rich in mucin, is called *mucous connective tissue.* In the mucin or ground substance are found irregular branching cells and small bundles of white fibrils. Some authorities class Wharton's jelly [1] in the umbilical cord and the vitreous body found in the posterior four-fifths of the bulb of the eye as mucous connective tissue.

[1] Thomas Wharton, English anatomist, 1621–1675.

2. Areolar connective tissue. — This tissue is composed of cells which vary in size and shape, and are separated from each other by a semi-fluid ground substance which also contains an irregular network of white fibers and yellow elastic fibers. The fibers are the predominant characteristic of the tissue.

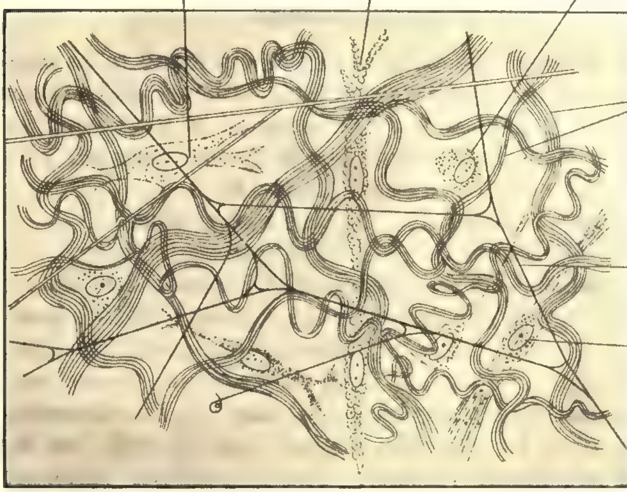


FIG. 22. — AREOLAR CONNECTIVE TISSUE FROM A YOUNG RABBIT. (Highly magnified.) The white fibers are in wavy bundles, the elastic fibers form an open network. The ground substance in which the cells and fibers lie is shaded. (Schäfer.)

Function. — Areolar connective tissue serves to connect and insulate entire organs. It is found under the skin (subcutaneous), under the mucous membrane (submucous), and filling in the spaces between the blood-vessels and nerves. Moreover, it is continuous throughout the body, and from one region it may be traced into any other, however distant, — a fact not without interest in practical medicine, as in this way air, water, pus, and other fluids, effused into the areolar connective tissue, may spread far from the spot where they were first introduced or deposited.

3. Adipose tissue. — Adipose tissue is areolar connective tissue in which some of the cells are filled with fat. Adipose tissue exists very generally throughout the body accompanying the still more widely distributed areolar tissue in most parts, though not in all, in which the latter is found. It is found chiefly:

(1) Underneath the skin, in the subcutaneous layer.

(2) Beneath the serous membranes or in their folds.

(3) Collected in large quantities around certain internal organs, especially the kidneys, helping to hold them in place.

(4) Filling up furrows on the surface of the heart.

(5) As padding around the joints.

(6) In large quantities in the marrow of the long bones.

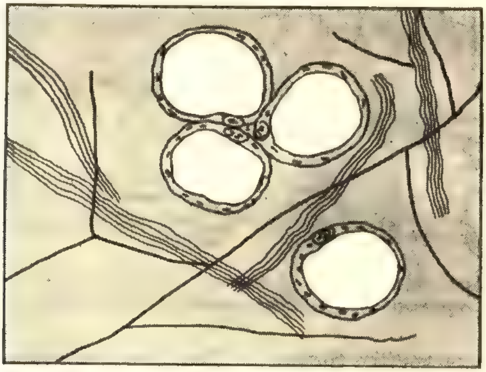


FIG. 23. — THIN SECTION OF CONNECTIVE TISSUE CONTAINING ADIPOSE CELLS. (Very highly magnified.) The background is matrix, the fibrous fibers are in wavy bundles, the elastic fibers are thinner and straighter. Four fat-containing cells are shown, the white center representing fat, surrounded by a protoplasmic envelope containing a nucleus.

Function. — Adipose tissue (1) constitutes an important reserve food, which when needed can be returned to the cells by the blood and oxidized, thus producing energy; (2) serves as a jacket or covering under the skin, and being a non-conductor of heat, prevents the too rapid loss of heat through the skin; (3) supports and protects various organs, *e.g.*, the kidneys; and (4) serves to fill up spaces in the tissues, thus affording support to delicate structures such as blood-vessels and nerves.

4. Liquid tissues. — Blood and lymph may be classified as liquid tissues. They consist of cells and an intercellular substance which is liquid. (See Chapters XI and XV.)

5. Reticular[2] **or retiform tissue.** — Reticular tissue is like areolar tissue with a network or reticulum of white fibers. The cells are in the form of broad thin plates wrapped around the fibers.

Lymphoid or adenoid[3] *tissue* is reticular tissue in which the meshes of the network are occupied by lymph cells. This is the most common condition of retiform tissue.

Function. — Reticular tissue forms a supporting framework in the lymph-nodes, in bone marrow, and in muscular tissue. It is

[2] Reticulum (from the Latin *reticulum*, "a small net"). Resembling a small net.

[3] Adenoid (from the Greek *aden*, "a gland," and *eidos*, "resemblance"). Pertaining to or resembling a gland.

also present in the spleen, in the mucous membrane of the gastro-intestinal tract, in the lungs, liver, and kidneys.

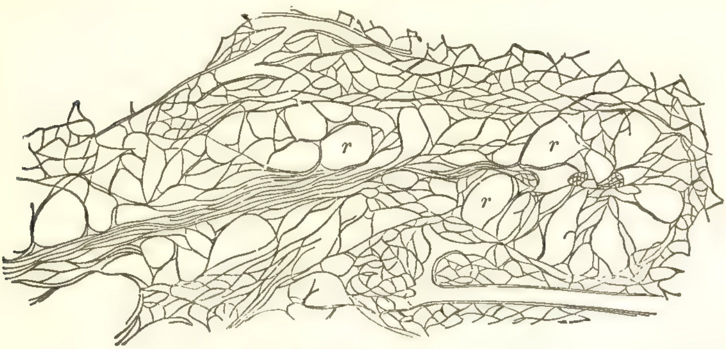


FIG. 24. — THIN SECTION OF RETIFORM TISSUE FROM A LYMPH-NODE. *r*, *r*, *r*, represent lymph-filled meshes of this tissue. (Quain.)

6. Elastic connective tissue. — This tissue consists of cells with few white fibers and a predominance of yellow fibers which give it a yellowish color.

Function. — Elastic tissue is extensile and elastic. Wherever located it does such work as India rubber would do. It is found:

(1) Between the laminæ of adjacent vertebræ. (*Ligamenta flava*).

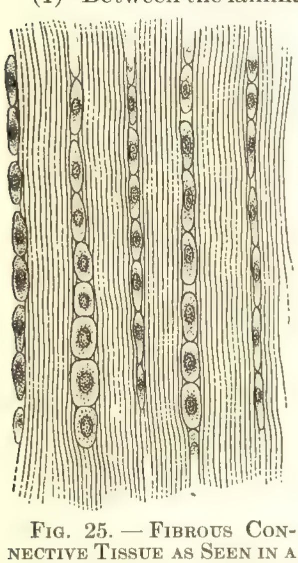


FIG. 25. — FIBROUS CONNECTIVE TISSUE AS SEEN IN A THIN LONGITUDINAL SECTION OF A TENDON. The spaces between the bundles of fibers are occupied by rows of cells.

(2) In the walls of the blood-vessels (especially arteries), bronchial tubes, and vocal folds.

(3) Entering into the formation of the lungs and uniting the cartilages of the larynx.

7. Fibrous connective tissue. — This tissue consists almost wholly of wavy white fibers, which cohere very closely and are arranged side by side in bundles which have an undulating outline. The spaces between the bundles are occupied by cells arranged in rows, but the cells are not a prominent feature of this tissue.

Fibrous tissue is white, strong, and tough, yet perfectly pliant; it is almost devoid of extensibility and is very sparingly supplied with nerves and blood-vessels.

Function. — Fibrous connective tissue is part of the supporting framework of the body. It forms:

(1) *Ligaments,* strong flexible bands, or capsules, of fibrous tissue that help to hold the bones together at the joints.

(2) *Tendons or sinews,* white glistening cords or bands which serve to attach the muscles to the bones.

(3) *Aponeuroses,* flat, wide bands of fibrous tissue which connect one muscle with another or with the periosteum of bone.

(4) *Membranes* containing fibrous tissue found investing and protecting different organs of the body, *e.g.*, the heart and the kidneys.

(5) *Fasciæ.* The word *fascia* means a band or bandage. It is most frequently applied to sheets of fibrous membrane which are wrapped around muscles, and serve to hold them in place. Fasciæ are divided into two groups, (*a*) superficial and (*b*) deep.

a. Superficial fascia, composed of subcutaneous areolar connective tissue, forms a nearly continuous covering beneath the skin. It varies in thickness, and usually permits free movement of the skin on the subjacent parts.

Infection of the superficial fascia is called *cellulitis.* In this loose areolar connective tissue infection spreads readily and it is difficult to keep it from extending to surrounding areas.

b. Deep fasciæ are sheets of white, flexible fibrous tissue, employed to envelop and bind down the muscles, also to separate them into groups. The term *fasciæ,* unless limited by an adjective, is usually employed to designate the *deep fasciæ.* Subcutaneous areolar tissue is rarely called by the name fascia, though it is correctly classed as such.

Areolar, elastic, and fibrous connective tissue agree closely with one another in elementary structure. It is the different arrangement of the cells and fibers, and the relative proportion of one kind of fiber to the other, that give them their different characteristics.

8. Neuroglia tissue. — This variety of connective tissue consists of cells called *glia cells,* which give off numerous processes. The processes extend in all directions and intertwine among the nerve cells of the brain and spinal cord. Neuroglia is derived from the ectoderm.

9. Cartilage. — This is the well-known substance called *gristle.* It is firm, tough, and elastic. When a very thin section is examined with a microscope, it is seen to consist of groups of cells in a mass of intercellular substance called the matrix. According to the texture of the intercellular substance, we distinguish three principal varieties:

(1) *Hyaline or true cartilage.*
(2) *White fibrocartilage.*
(3) *Yellow or elastic cartilage.*

Hyaline cartilage. — This variety is named from the Greek word for glass. Comparatively few cells are embedded in an abundant

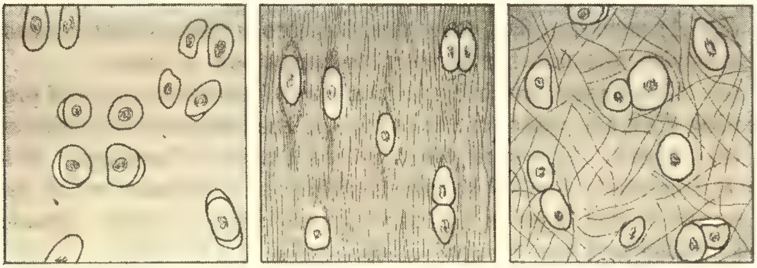


FIG. 26. — *A*. Thin section of hyaline cartilage. Groups of cartilage cells in an apparently homogeneous matrix. *B*. Section of fibrous cartilage. *C*. Section of elastic cartilage.

quantity of intercellular substance which appears homogeneous, but is made up of fibers quite similar to those found in fibrous connective tissue.

(*a*) Hyaline cartilage covers the ends of the bones in the joints, where it is known as articular cartilage.

(*b*) Hyaline cartilage forms the rib cartilages, where it is known as costal cartilage.

In both these situations the cartilages are in immediate connection with bone, and may be said to form part of the skeleton, hence are frequently described as skeletal cartilages.

Function. — In covering the ends of the bones in the joints, the articular cartilages provide these harder parts with a thick, springy coating, which breaks the force of concussion, and gives ease to the motion of the joints. In forming part of the solid framework of the thorax or chest, the costal cartilages impart elasticity to its walls. Hyaline cartilage enters into the formation of the nose, ears, larynx, and trachea.

In the embryo a type of hyaline cartilage, known as embryonal cartilage, forms the matrix in which most of the bones are developed.

White fibrocartilage. — The intercellular substance is pervaded with bundles of white fibers, between which are scattered cartilage cells. It closely resembles white fibrous tissue.

White fibrocartilage is found joining bones together, the most familiar instance being the flat round plates or discs of fibro-

cartilage connecting the bodies of the vertebræ and between the pubic bones. In these cases the part in contact with the bone is always hyaline cartilage, which passes gradually into fibrocartilage.

Function. — It serves as a strong, flexible, connecting material between bones and is found wherever great strength combined with a certain amount of rigidity is required.

Yellow or elastic cartilage. — The intercellular substance is pervaded with yellow elastic fibers which form a network. In the meshes of the network the cartilage cells are found. This form of cartilage is found in the epiglottis, cartilages of the larynx, auditory tube, and external ear.

Function. — It strengthens and maintains the shape of these organs, and yet allows of a certain amount of elasticity.

Cartilage is not supplied with nerves, and very rarely with blood-vessels. *Perichondrium,* a moderately vascular fibrous membrane, covers and nourishes cartilage except where it forms articular surfaces.

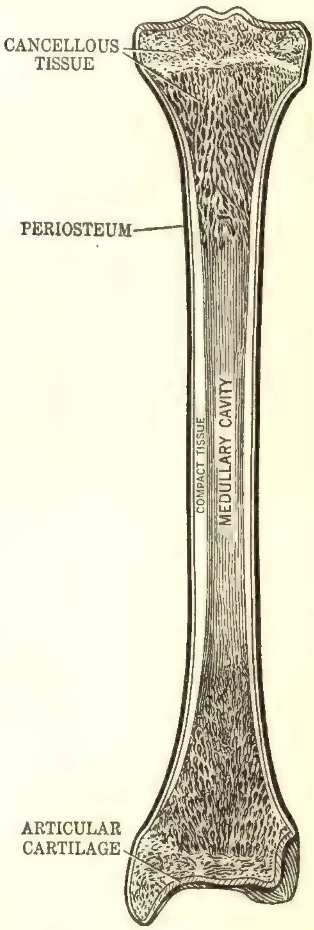


FIG. 27. — LONGITUDINAL SECTION OF A LONG BONE.

10. Bone or osseous tissue. — Bone is connective tissue in which the intercellular substance is rendered hard by being impregnated with mineral salts, chiefly the phosphate and the carbonate of calcium. The mineral salts or inorganic matter constitute about two-thirds of the weight of bone. The organic matter, consisting of cells, blood-vessels, and gelatinous substance, constitutes about one-third. The inorganic matter can be dissolved out by soaking a bone in dilute acid, or the organic matter may be driven off by heat. In both cases the shape of the bone will be preserved. Bone freed from inorganic matter is called *decalcified.* It is a tough, flexible, elastic substance, so free from stiffness that it can be tied in a knot. Bone freed from organic

matter is white, rigid, and so brittle that it can be crushed in the fingers.

Structure of bone. — On sawing a bone it will be seen that in some parts it consists of slender fibers and lamellæ which form a structure resembling lattice-work, whilst in others it is dense and close in texture, appearing like ivory. We thus distinguish two forms of bony tissue:

(1) *The cancellated, or spongy.*

(2) *The dense, or compact.*

On closer examination, it will be seen that all bone is porous, the difference between the two forms being only a matter of degree. The compact tissue has fewer spaces and more solid matter between them, while the cancellated has larger cavities and more slender intervening bony partitions. The compact tissue is always found on the exterior of a bone and the cancellous in the interior. The relative quantity of these two kinds of tissue varies in different bones and in different parts of the same bone, depending on the need for strength or lightness. The shafts of the long bones are made up almost entirely of compact tissue, except that they are hollowed out to form a central canal, — the medullary canal, — which is lined by a vascular tissue called the medullary membrane.

Fig. 28. — Section through the Upper End of Femur Showing Cancellated Structure of the Bone.

Marrow. — There are two distinct kinds of marrow, red and yellow.

Red marrow consists of (1) a small amount of connective tissue that acts as a support for a large number of blood-vessels, (2) a large number of marrow cells or *myelocytes*, which resemble the white blood cells, (3) a small number of fat cells, (4) a number of cells called *erythroblasts* from which the red blood cells are derived; and (5) *giant cells* (*osteoclasts*) found in both kinds of marrow but more abundant in the red marrow. Red marrow is found in the articular ends of the long bones and in the cancellous tissue.

Yellow marrow consists of connective tissue supporting numerous blood-vessels and cells. Most of the cells are fat cells, only a few are myelocytes. It is found in the medullary canals of the long

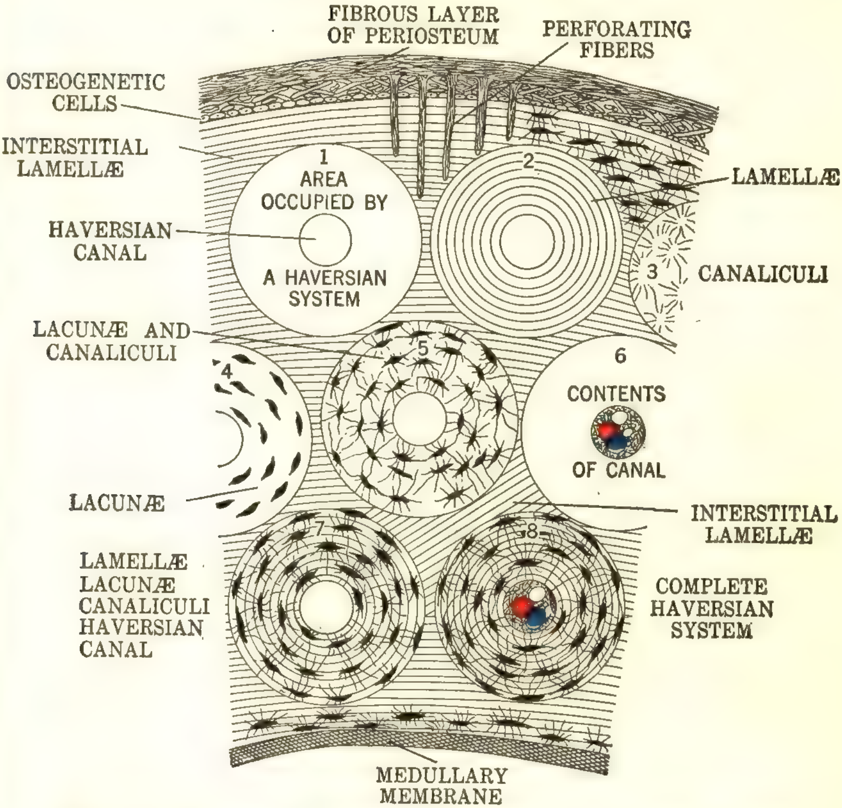


FIG. 29. — DIAGRAM TO SHOW THE STRUCTURE OF OSSEOUS TISSUE. Details are drawn to a very much larger scale than the complete drawing. A small part of a transverse section of a long bone is shown. At the uppermost part is the periosteum, covering the outside of the bone; at the lowermost part is the medullary membrane, lining the marrow cavity. Between these is compact tissue, consisting largely of a series of Haversian systems, each being circular in outline and perforated by a central canal, left blank in the canals of five of the systems, in this illustration, and represented in color in two. The *first* circle shows the area occupied by a system. The *second* shows the layers of bony tissue, or lamellæ, arranged around the central canal.

In the *third*, fine dark radiating lines represent canaliculi, or lymph channels. In the *fourth*, dark spots arranged in circles between the lamellæ represent lymph spaces, or lacunæ, which contain the bone cells. In the *fifth*, the central canal, lacunæ and canaliculi, which connect the lacunæ with each other and with the central canal, are shown.

The *sixth* shows the contents of the canal: artery, veins, lymphatics, and areolar tissue. The *seventh* shows the lamellæ, lacunæ, canaliculi, and Haversian canal. The *eighth* shows a complete Haversian system.

Between the systems are interstitial lamellæ, only a few of which are represented as lodging lacunæ, though lacunæ are in all parts. The periosteum is seen to be made up of an outer fibrous layer and an inner osteogenetic layer, so called because it contains bone-forming cells, called osteoblasts.

bones and extends into the spaces of the cancellous tissue and the Haversian[4] canals. It is thought that in the adult the white cells of the blood are formed in the marrow tissue from its myelocytes.

Periosteum. — All bones are covered, except at their cartilaginous extremities, by a membrane called periosteum (around the bone). It consists of an outer layer of connective tissue and an inner layer of fine fibers which form dense networks. In young bones the periosteum is thick, vascular, and closely connected with the epiphyseal cartilages. Later in life the periosteum is thinner and less vascular.

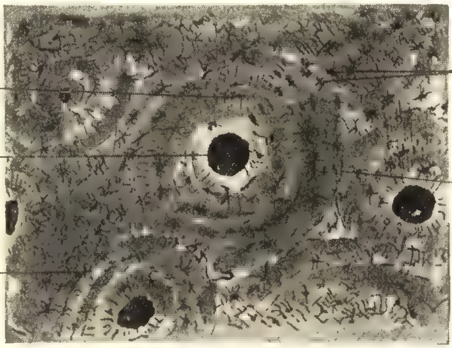


Fig. 30. — Photomicrograph of a Thin Section of Osseous Tissue.

Blood-vessels and nerves. — Unlike cartilage, the bones are plentifully supplied with blood. If we strip the periosteum from a fresh bone, we see many bleeding points representing the canals (Volkmann's[5]) through which the blood-vessels enter and leave the bone. These blood-vessels proceed from the periosteum to join the system of Haversian canals. Around the Haversian canals the lamellæ are disposed, while lying between them, arranged in circles, are found the lacunæ, which contain the bone cells. Radiating from one lacuna to another and toward the center are the canaliculi. Following this scheme, it will be seen that the innermost canaliculi run into the Haversian canals; thus direct communication is established between the blood in these canals and the cells in the lacunæ surrounding the Haversian canals. The marrow in the body of a long bone is supplied by one large artery (sometimes more) called the *medullary* or *nutrient* artery, which enters the bone at the nutrient foramen, situated in most cases near the center of the body, and perforates the compact tissue obliquely. It sends branches

[4] Clopton Havers, English anatomist, 1650–1702.
[5] Alfred Wilhelm Volkmann, German physiologist, 1800–1877.

upward and downward which ramify in the marrow, and enter the adjoining bony tissue. The twigs of these vessels anastomose with the arteries of the compact and cancellous tissue. In this way the whole substance of the bone is penetrated by intercommunicating channels carrying nutrient matters and mineral salts from the blood to every part. In most of the flat, and in many of the short spongy bones, larger apertures give entrance to vessels which pass to the central parts of the bone and correspond to the nutrient arteries of the long bones.

Lymphatic vessels have been traced into the substance of bone and accompany the blood-vessels in the Haversian canals. The periosteum is well supplied with nerves, which accompany the arteries into the bone.

Development of bones. — In the early embryo, some bones, such as those forming the roof and sides of the skull, are preformed in

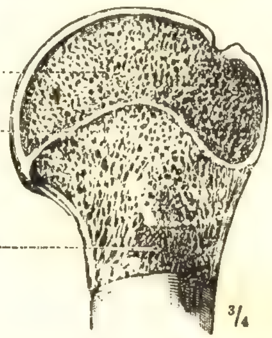


FIG. 31. — THE COMMON EPIPHYSIS OF THE PROXIMAL EXTREMITY OF THE HUMERUS, FROM A BOY OF THIRTEEN YEARS.

membrane; others, such as those of the limbs, are preformed in rods of cartilage covered by membrane. Hence two kinds of ossification occur, the intramembranous and the intracartilaginous.

Intramenbranous ossification. — Before the cranial bones are formed the brain is covered by inner meningeal membranes, a middle fibrous membrane, and an outer layer of skin. The fibrous membrane occupies the place of the future bone. From it periosteum and bone are formed. It is composed of fibers and granular cells called osteoblasts [6] in a matrix or ground substance. When bone begins to form, a network of spicules radiates from a point or center of ossification. These spicules develop into fibers. Lime salts are deposited in the fibers and matrix, enclosing some of the osteoblasts in tiny spaces called lacunæ. As the fibers grow out

[6] Osteoblasts are bone-forming cells.

they continue to calcify, and give rise to fresh bone spicules. Thus a network of bone is formed, the meshes of which contain the blood-vessels, and a delicate connective tissue crowded with osteoblasts. The bony network thickens by the addition of fresh layers of bone formed by the osteoblasts and the meshes are correspondingly encroached upon. Successive layers of bony tissue are deposited under the periosteum, so that the bone increases much in thickness, and presents the structure of compact bone on the outer and inner surfaces with a layer of soft, spongy, cancellated tissue between. The cancellated tissue between the layers or tables of the skull is called the *diploë*. Ossification of the bones of the skull is not complete at birth. At the site of the future union of two or more bones, membranous areas persist and are called fontanels.

Intracartilaginous ossification. — By the end of the second month the skeleton of the embryo is preformed in cartilage. Soon after this ossification begins. The first step in intracartilaginous ossification is that the cartilage cells at the center of *ossification* enlarge and arrange themselves in rows. Following enlargement, lime is deposited in the matrix between the cells, first separating them and later surrounding them so that all nutriment is cut off, resulting in their atrophy and disappearance. While this process is in progress in the center of the cartilage other changes are occurring on its surface. The membrane called perichondrium which covers the cartilage assumes the character of periosteum. From this membrane grow cells which are deposited in the spaces left by the atrophy of the cartilage cells. These two processes, destruction of cartilage cells and the formation of bone cells to replace them, continue until ossification is complete. The number of centers of ossification varies in differently shaped bones. In most of the short bones ossification begins at a point near the center and proceeds toward the surface. In the long bones, there is first a center of ossification for the body called the *diaphysis* and one or more centers for each extremity called the *epiphyses*. Ossification proceeds from the diaphysis toward the epiphysis, and from the epiphysis toward the diaphysis. As each new portion is ossified thin layers of cartilage continue to develop between the diaphysis and epiphysis and during the period of growth these outstrip ossification. When this ceases, the growth of a bone stops.

Ossification begins soon after the second month of intrauterine life and continues well into adult life. Such bones as the sternum, the sacrum, and the hip bones do not unite to form single bones until the individual is well beyond twenty-one years of age.

From this brief discussion two points of practical interest stand out: (1) the bones of the new-born infant are soft and largely composed of cartilage; (2) since the process of ossification is going on continually, the proper shape of the cartilage should be preserved in order that the shape of the future bone may be normal. Therefore it is obvious that a young baby's back should be supported, and a child should always rest in a horizontal position. The facility with which bones may be moulded and become misshapen is seen in the flattening of the head of some Indians who bind a board across the top of the infant's skull; in the bow-legs of children, and in the distortion of the feet of Chinese ladies of the old régime. However, the softness of the skeleton of a child accounts for the fact that the many jars and tumbles experienced in early life are not as injurious to the cartilaginous frame as they would be to a harder structure.

Numerous experiments have demonstrated that the proper ossification and growth of bone depend upon (1) adequate amounts of calcium and phosphorus in the food and (2) chemical substances which enable the bone cells to utilize calcium and phosphorus. The chemical substances may be vitamins derived from food or an autacoid like thyroxin derived from the internal secretion of the thyroid. Milk contains well-balanced proportions of calcium and phosphorus, hence the dietary rule of a quart of milk each day for every child.

Rickets or rachitis. — Rickets is a condition in which the mineral metabolism is disturbed in such a way that calcification of the bones does not take place normally. The bones remain soft and become misshapen, resulting in bow-legs and malformations of the head, chest,[7] and pelvis.

Sunlight, either direct rays of sun or from a mercury vapor quartz lamp, adequate amounts of calcium and phosphorus in food, and the antirachitic vitamin (D) found in cod-liver oil and in smaller amounts in egg yolk, whole milk, and fresh vegetables are important factors in the prevention and cure of rickets.

Dr. Edwards A. Park, professor of pediatrics in Johns Hopkins University, states: "Personally I believe that if pregnant women received ample well-balanced diets, in which green vegetables were abundantly supplied and cows' milk was regularly taken, and kept a sufficient part of their time in the open air and sun, and if their infants were placed in the direct rays of the sun for a part of each day and were fed cod liver oil for the first two or three years of life, more could be accomplished in regard to the eradication of caries of the teeth than in all other ways put together, and that rickets would be abolished from the earth."

Fracture. — The term *fracture* is applied to the breaking of a bone which may be either partial or complete. As a result of the greater amount of organic matter in the bones of children, they are flexible, bend easily, and do not break readily. In some cases the bone bends like a bough of green wood. Some of the fibers may break, but not the whole bone, hence the name *green-stick fracture.* The greater amount of inorganic matter in the bones of the

[7] One of the early findings is the so-called "rachitic rosary."

aged renders the bones more brittle, so that they break easily and heal with difficulty.

Regeneration of bone. — A fracture is usually accompanied by injury to the periosteum and tissues. This results in inflammation, which means that an increased amount of blood is sent to the part. The plasma and white cells from the blood exude into the tissues and form a viscid substance, which sticks the ends of the bone together, and is called *callus.* Usually bone cells from the periosteum and lime salts are gradually deposited in the callus, which eventually becomes hardened and forms new bone. Occasionally the callus does not ossify and a condition known as *fibrous union* results. The periosteum is largely concerned in the process of repair; for if a portion of the periosteum be stripped off, the subjacent bone will be liable to die, while if a large part or the whole of a bone be removed, and the periosteum at the same time left intact, the bone will wholly or in a great measure be regenerated.

SUMMARY

Classification of Tissues { Connective. Muscular. Nerve. Epithelial.

Connective Tissue. — A tissue of cells with a great deal of intercellular substance, which is derived from the cells.

Characteristics {
1. Cellular element at a minimum, intercellular element abundant.
2. With the exception of neuroglia they develop from the mesoderm.
3. Serve to connect and support other tissues.
4. They originate no action, but are acted upon by other tissues.
5. With the exception of cartilage, they are highly vascular.

Varieties				
	Embryonal.	Liquid tissues.	Fibrous.	Bone.
	Areolar.	Reticular.	Neuroglia.	
	Adipose.	Elastic.	Cartilage.	

Embryonal Tissue. — Represents a stage in development of connective tissue. Consists of cells and a primitive intercellular ground substance. When ground substance is rich in mucin it is called mucous connective tissue.

Areolar Tissue. — Formed by interlacing of wavy bundles of white fibers and some straight elastic fibers with cells lying in the ground substance.

Function. — Connects, insulates, forms protecting sheaths, and is continuous throughout the whole body.

Adipose Tissue. — Modification of areolar tissue, with cells filled with fat. Distribution quite general but not uniform.

Function {
1. Forms a reserve fund to be drawn upon in time of need.
2. Prevents the too rapid loss of heat.
3. Serves to protect and support delicate organs.

Liquid Tissues. — Cells in a liquid intercellular substance, *e.g.*, blood and lymph.

Reticular Tissue. — Is areolar tissue with a network of white fibers. Cells wrapped around fibers.

Lymphoid tissue. — Reticular tissue with meshes of network occupied by lymph cells.

Function. — Reticular tissue forms a supporting framework in many organs, *e.g.*, lymph-nodes, bone marrow, and muscular tissue. Reticular tissue is present in the spleen, mucous membrane of the gastro-intestinal tract, lungs, liver, and kidneys.

Elastic Tissue. — Consists of cells with few white fibers and a predominance of yellow fibers.

Function. — It is extensile and elastic. Found in ligamenta flava, blood-vessels, air tubes, vocal folds, lungs, and larynx.

Fibrous Tissue. — Formed of wavy bundles of white fibers only, with cells in rows between bundles. Very strong and tough but pliant.

Function. — Is found in form of ligaments, tendons, aponeuroses, protecting sheaths, and fasciæ.

Neuroglia Tissue. — Consists of glia cells which give off processes that extend in all directions.

Function. — Forms a supporting network for the nerve cells of the brain and spinal cord.

Cartilage. — Cartilage consists of a group of cells in a matrix. It is firm, tough, and elastic, covered and nourished by perichondrium.

Varieties
1. **Hyaline Cartilage.** { Articular, Costal } Skeletal.
2. **White Fibrocartilage.**
3. **Yellow Elastic Cartilage.**

Bone or Osseous Tissue. — Bone is connective tissue in which the intercellular substance derived from the cells is rendered hard by being impregnated with mineral salts.

BONE OR OSSEOUS TISSUE

- **Composition**
  - *Inorganic Matter* (about 67%)
    - Calcium phosphate about 58%
    - Calcium carbonate about 7%
    - Calcium fluoride about 1–2%
    - Magnesium phosphate about 1–2%
    - Sodium chloride less than 1%
  - *Organic Matter* (about 33%)
    - Cells
    - Blood-vessels
    - Gelatinous substance
- **Varieties**
  - Cancellated or spongy.
  - Dense or compact like ivory.
- **Canals**
  - Medullary — Red and yellow marrow.
  - Haversian
    - Blood-vessels.
    - Lymphatics.
- **Haversian System**
  - Haversian canals are surrounded by lamellæ, lacunæ, and canaliculi.
  - Lamellæ — bony fibers arranged in rings around Haversian canals.
  - Lacunæ — hollow spaces between lamellæ occupied by bone cells.
  - Canaliculi — canals which radiate from one lacuna to another and toward the Haversian canals.
- **Medullary Membrane.** — A vascular tissue that lines the medullary canal.
- **Marrow**
  - Red — Consists of connective tissue supporting blood-vessels, myelocytes, fat cells, erythroblasts from which red blood cells are derived, and giant cells. Found in the marrow cavity at the end of long bones and in cancellous tissue.
  - Yellow — Contains more connective tissue and fat cells than red marrow, fewer myelocytes, few if any red cells, and fewer giant cells. White cells of blood and lymph are derived from its myelocytes. Found in the medullary canals of the long bones.

Periosteum. — A vascular fibrous membrane that covers the bones except at their cartilaginous extremities and serves to nourish them. Important in the reunion of broken bone and growth of new bone.

Blood-vessels. — Twigs of nutrient artery in medullary canal anastomose with twigs from Haversian canals; and these in turn anastomose with others which enter from periosteum.

Development of bone
- In the embryo bones are preformed in membrane and cartilage.
- **Ossification**
  - Intramembranous.
  - Intracartilaginous.
- **Dependent upon**
  - Adequate amounts of calcium and phosphorus in food.
  - Vitamins and autacoids.

Rickets
- Mineral metabolism disturbed.
- Calcium and phosphorus in food necessary.
- Sunlight needed.
- Antirachitic vitamin in milk, vegetables (also in cod-liver oil) needed.

CHAPTER V

THE SKELETON: BONES OF THE CRANIUM, FACE, TRUNK, UPPER EXTREMITIES, AND LOWER EXTREMITIES

The **bones** are the principal organs of support, and the passive instruments of locomotion. Connected together in the skeleton, they form a framework of hard material to which the skeletal muscles are attached. This framework affords attachment for the soft parts, maintains them in position, shelters such as are of delicate structure, gives stability to the whole fabric, and preserves its shape.

The skeleton in the adult consists of two hundred and six named bones. These are:

Cranium	8	
Face	14	
Ear: Malleus 2, Incus 2, Stapes 2	6	
Hyoid	1	206
The spine, or vertebral column (sacrum and coccyx included)	26	
Sternum and ribs	25	
Upper extremities	64	
Lower extremities	62	

In this enumeration the sesamoid[1] and Wormian[2] bones are not included. Sesamoid bones are found embedded in the tendons covering the bones of the knee, hand, and foot. Wormian bones are small isolated bones which occur in the course of the sutures, most frequently the lambdoidal suture.

Classification. — The bones may be divided according to their shape, into four classes: 1. *Long*, 2. *Short*, 3. *Flat*, and 4. *Irregular*.

A long bone consists of a shaft and two extremities. The shaft is formed mainly of compact tissue, this compact tissue being thickest in the middle, where the bone is most slender and the strain greatest, and it is hollowed out in the interior to form the *medullary canal*. The extremities are made of cancellated tissue with only a thin coating of compact tissue, and are more or less expanded for greater convenience of mutual connection, and to afford a broad surface for muscular attachment. All long bones are more or less

[1] Ses′amoid [from the Greek *sesamon*, a "seed of the sesamum," and *eidos*, "form," "resemblance"], resembling a grain of sesame.

[2] Olaus Worm, Danish anatomist, 1588–1654.

curved, which gives them greater strength. They are found in the extremities, *e.g.*, humerus.

The *short bones* are small pieces of bone irregularly shaped. Their texture is spongy throughout, excepting at their surface,

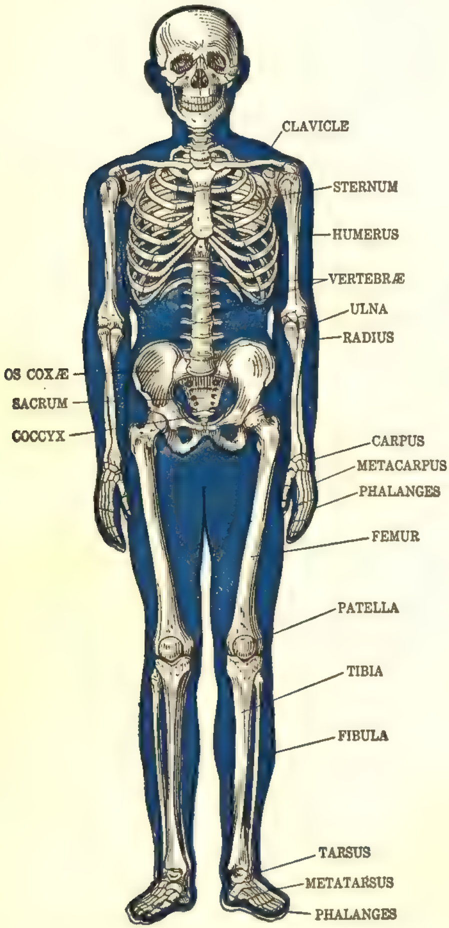


FIG. 32. — THE HUMAN SKELETON. (Front View.)

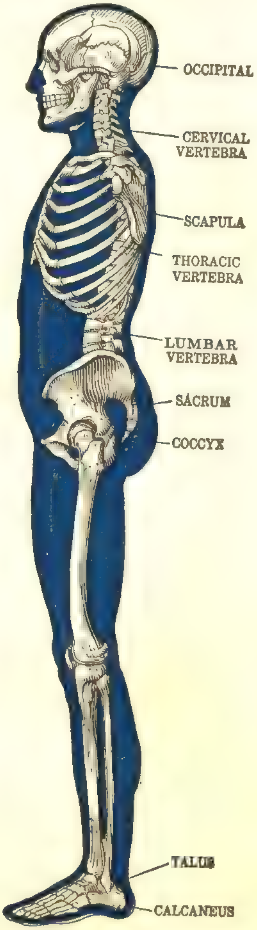


FIG. 33. — THE HUMAN SKELETON. (Side View.)

where there is a thin crust of compact tissue. The short bones are the sixteen bones of the carpus, the fourteen bones of the tarsus, and the two patellæ.

Where the principal requirement is either extensive protection or the provision of broad surfaces for muscular attachment, we find *flat bones*. The bony tissue expands into broad or elongated flat

plates which are composed of two thin layers of compact tissue, enclosing between them a variable quantity of cancellous tissue, *e.g.*, occipital bone.

The *irregular bones* are those which, on account of their peculiar shape, cannot be grouped under any of the preceding heads. A vertebra is a good example. The bones of the ear are so small that they are described as *ossicles* and do not fit in any of these groups.

Processes and depressions. — If the surface of any bone is examined, certain projections and depressions are seen. The projections are called *processes*. The depressions are called *fossæ* or *cavities*, and either a qualifying adjective is used to describe them, or a special name given to them. Processes and depressions are classified as: 1. **Articular, 2. Non-articular.** The articular are provided for the mutual connection of bones to form joints. The non-articular serve for the attachment of ligaments and muscles. The following terms are used:

Cavities

Fissure. — A narrow slit.

Foramen. — A hole or orifice through which blood-vessels, nerves, and ligaments are transmitted.

Meatus or Canal. — A long tube-like passageway.

Sinus [3] and *antrum* are applied to cavities within certain bones.

Groove or Sulcus. — A furrow.

Fossa. — A depression in or upon a bone.

Processes

Process. — Any marked bony prominence.

Condyle. — A rounded or knuckle-like process.

Tubercle. — A small rounded process.

Tuberosity. — A large rounded process.

Trochanter. — A very large process.

Crest. — A narrow ridge of bone.

Spine or Spinous Process. — A sharp, slender process.

Head. — A portion supported on a constricted part or neck.

DIVISIONS OF THE SKELETON

In taking up the various divisions of the skeleton, it will be considered as consisting of —

Axial Skeleton	1. Head or skull	Cranium. Face.
	2. Hyoid.	
	3. Trunk	Vertebræ. Sternum. Ribs.
Appendicular Skeleton	4. Upper extremities.	
	5. Lower extremities.	

[3] The term *sinus* is also used in surgery to denote a narrow tract leading from the surface down to a cavity.

The head or skull. — The head or skull rests upon the spinal column, and is composed of the cranial and facial bones. It is divisible into — **1. Cranium** or **brain case,** and **2. Anterior region** or **face.**

BONES OF THE CRANIUM

Occipital, base of skull	1	8
Parietal, crown	2	
Frontal, forehead	1	
Temporal, ear region	2	
Ethmoid, between cranial and nasal cavities	1	
Sphenoid, base of brain and back of orbit	1	

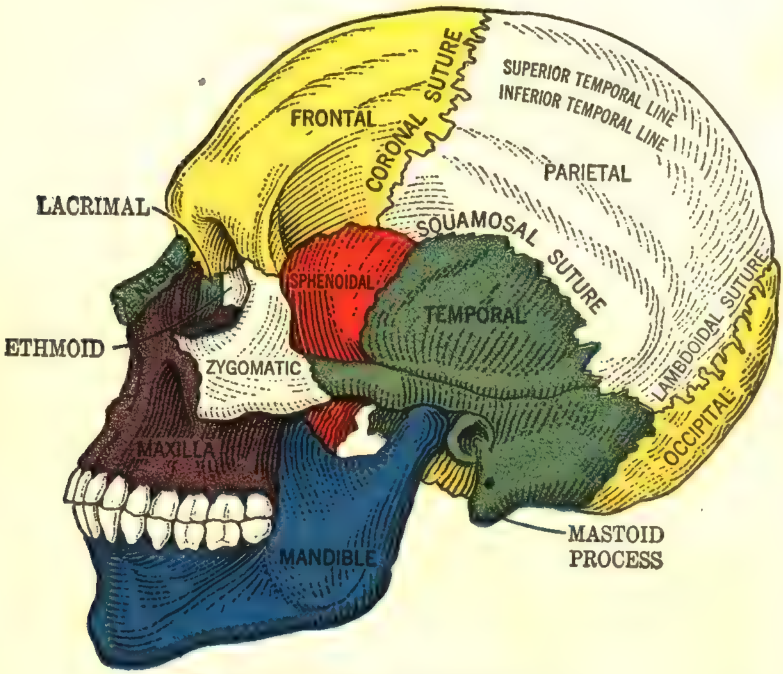


FIG. 34. — SIDE VIEW OF SKULL.

Occipital bone. — It is situated at the back and base of the skull. The internal surface is deeply concave, and presents many eminences and depressions for the reception of parts of the brain. There is a large hole — the *foramen magnum* — in the inferior portion of the bone, for the transmission of the medulla oblongata (the constricted portion of the brain) where it narrows down to join the spinal cord. At the sides of the foramen magnum it presents two processes called condyles, which articulate with the atlas.

The external surface is convex and presents midway between the summit of the bone and the foramen magnum a projection — the external occipital protuberance — which can be felt through the scalp. From this a median ridge — the external occipital crest — leads to the foramen magnum. The protuberance and crest give attachment to the ligamentum nuchæ.[4] Two curved lines extend

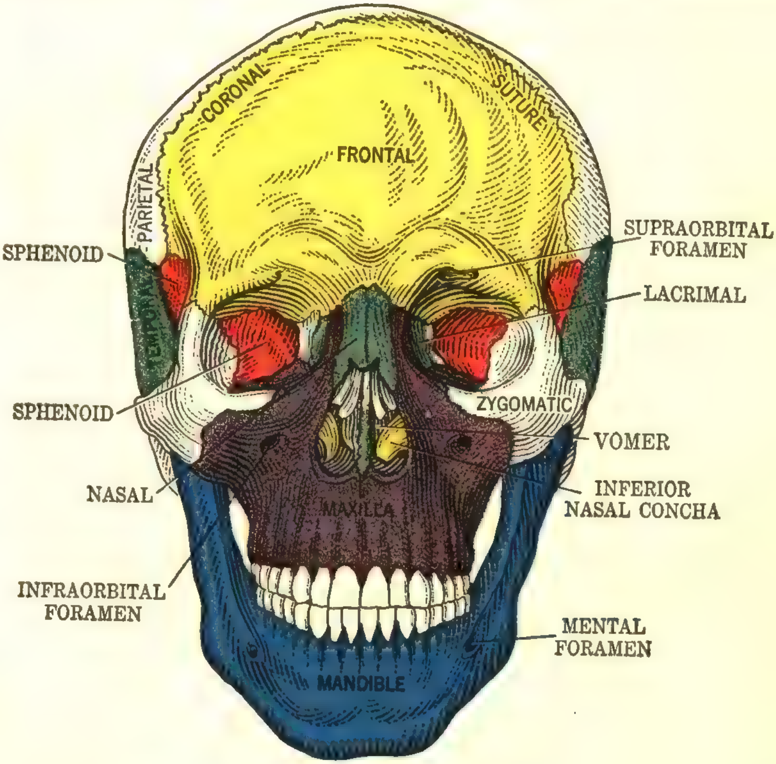


FIG. 35. — FRONT VIEW OF SKULL.

lateralward from the protuberance. These lines and the expanded plate behind the foramen magnum — the squama — serve for the attachment of several muscles.

Parietal bones. — The right and left form by their union the greater part of the sides and roof of the skull. The external surface is convex and smooth; the internal surface is concave, and presents eminences and depressions for lodging the convolutions of the brain, and numerous furrows for the ramifications of arteries which supply the dura mater (membrane which covers the brain) with blood.

[4] See Fig. 51.

Frontal bone. — It resembles a cockle shell, and not only forms the forehead, but also enters into the formation of the roof of the orbits, and of the nasal cavity. The arch formed by part of the frontal bone over the eye is sharp and prominent, and is known as the supraorbital margin. Just above the supraorbital margins are hollow spaces called the *frontal sinuses* which are filled with air and open into the nose. In the upper and outer angle of each orbit are two depressions called lacrimal fossæ for the reception of the glands of the same name, which secrete the tears. At birth the bone consists of two pieces, which afterwards become united

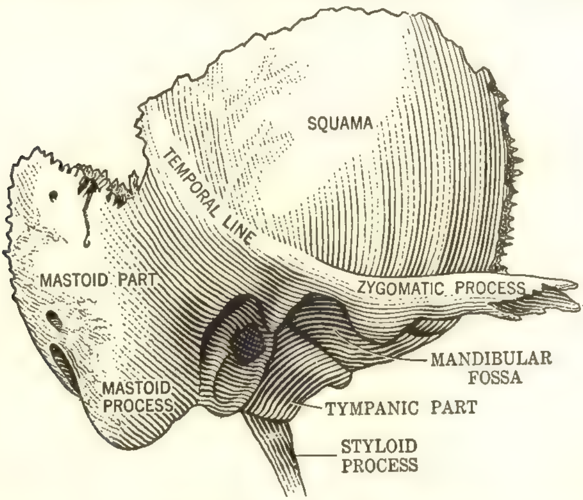


FIG. 36. — THE RIGHT TEMPORAL BONE, OUTER SURFACE.

along the middle line, by a suture which runs from the vertex of the bone to the root of the nose. This suture usually becomes obliterated within a few years after birth.

Temporal bones. — The right and left are situated at the sides and base of the skull. They are named temporal from the Latin word *tempus*, time, as it is on the temples the hair first becomes gray and thin, and thus shows the ravages of time. The temporal bones are divided into five parts, the squama, the petrous, mastoid, and tympanic parts, and the styloid process.

The *squama*, a thin, expanded portion, forms the anterior and upper part of the bone. A curved line — the temporal line or supramastoid crest — runs backward and upward across its posterior part. Projecting from the lower part of the squama is the long arched zygomatic process which articulates with the temporal process of the zygomatic bone.

The *petrous* portion is shaped like a pyramid and is wedged in at the base of the skull between the sphenoid and occipital bones. The internal ear, the essential part of the organ of hearing, is contained in a series of cavities channeled out of the substance of the petrous portion. Between the squamous and the petrous portions is a socket called the mandibular fossa for the reception of the condyle of the mandible.

The *mastoid* portion projects downward behind the opening of the meatus. It is filled with a number of connected cancellous spaces called mastoid cells which contain air. These cells communi-

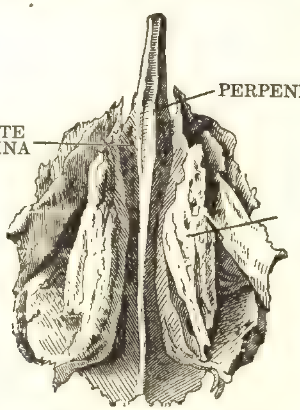


FIG. 37. — ETHMOID BONE. Seen from under surface.

cate with the cavity of the middle ear. The condition known as mastoiditis means inflammation of the lining of these cells. The bony partition between the mastoid cells [5] and the brain is thin. The danger in mastoiditis is that the infection may penetrate the bone, reach the meninges or coverings of the brain, and cause meningitis.[6] The purpose in operating is to effect external drainage and if possible prevent the infection reaching the meninges.

The *tympanic* portion is a curved plate of bone below the squama and in front of the mastoid process. It assists in the formation of the acoustic meatus leading to the internal ear.

The *styloid* is a slender pointed process that projects downward from the under surface of the temporal bone. To its distal part are attached ligaments and some of the muscles of the tongue.

[5] *Cells.* — The student must bear in mind that the word "cell" is used with two different meanings in anatomy. Histologically speaking, the word "cell" refers to one of the component units of the body, such as an "epithelial cell" or "nerve cell." In connection with the use of the words "mastoid cells" in the text, the word "cells" refers to tiny enclosed hollow chambers.

[6] Meningitis is inflammation of the meninges or coverings of the brain.

Ethmoid bone. — It is an exceedingly light cancellous bone consisting of a horizontal or cribriform plate, a perpendicular plate (see Fig. 37), and two lateral masses or labyrinths. The horizontal plate forms the roof of the nasal cavity and closes the anterior part of the base of the cranium. It is pierced by numerous foramina, through which the olfactory nerves pass to the mucous membrane of the nose. Projecting upward from the horizontal plate is a smooth triangular process called the crista galli,[7] which serves for the attachment of the falx cerebri. (See Fig. 39.) Descending from the horizontal plate is the perpendicular plate which helps to form the upper part of the nasal septum. On either side, the lateral masses form part of the orbit and part of the corresponding nasal cavity. The lateral masses contain a number of thin-walled cavities called the ethmoidal sinuses, which communicate with the nasal cavity. Descending from the horizontal plate on either side of the septum are two processes of very thin, cancellous, bony tissue, named the superior and middle conchæ.

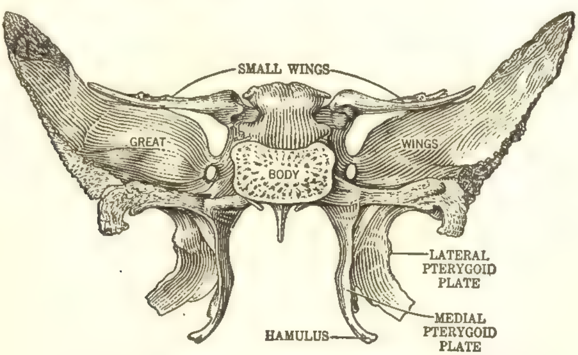


FIG. 38. — THE SPHENOID BONE, SEEN FROM BEHIND.

Sphenoid bone. — It is situated at the anterior part of the base of the skull and binds the other cranial bones together. In form it somewhat resembles a bat with extended wings, and consists of a body, two great and two small wings extending outward from the sides of the body, and two pterygoid processes which project downward. The body is joined to the ethmoid in front and the occipital behind. It contains cavities which are called sphenoidal sinuses. These sinuses communicate with the naso-pharynx. The upper portion of the body presents a fossa with anterior and posterior eminences. This is called the *sella turcica,* from its resemblance to a Turk's saddle. The hypophysis is lodged in the sella turcica.

[7] So-called from its resemblance to a cock's comb.

BONES OF THE FACE[8]

Nasal	2	14
Vomer	1	
Inferior nasal concha (Inferior turbinated)	2	
Lacrimal	2	
Zygomatic (malar)	2	
Palatine (palate)	2	
Maxilla (upper jaw)	2	
Mandible (lower jaw)	1	

Nasal bones. — They are two small oblong bones placed side by side at the middle and upper part of the face, forming by their junction the upper part of the bridge of the nose, the lower part being formed by the nasal cartilages.

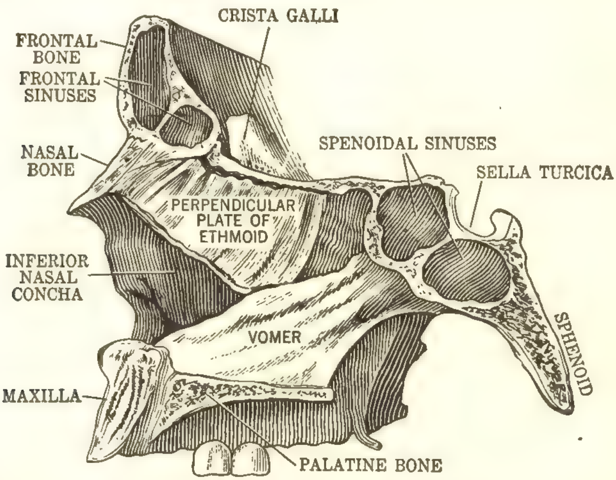


FIG. 39. — SAGITTAL SECTION OF FACE, A LITTLE TO THE LEFT OF THE MIDDLE LINE, SHOWING THE VOMER AND ITS RELATIONS. (Gerrish.)

Vomer. — It is a single bone placed at the lower and back part of the nasal cavity, and forms part of the central septum of the nasal cavity. It is thin, and shaped somewhat like a plowshare, but varies in different individuals, being frequently bent to one or the other side, thus making the nasal chambers of unequal size.

Inferior nasal conchæ (turbinated bones). — They are situated in the nostril, on the outer wall of each side. Each consists of a layer of thin, cancellous bone, curled upon itself like a scroll. They are below the superior and middle conchæ of the ethmoid bone.

[8] In the Basle Nomenclature (see page 105) the inferior nasal conchæ, the lacrimals, the nasals, and the vomer are classed as cranial and not as facial bones because they develop in connection with the nasal capsule.

Abnormal conditions of these bones and the membranes covering them cause some of the more common nasal diseases.

Lacrimal bones. — They are situated at the front part of the inner wall of the orbit, and somewhat resemble a finger-nail in form, thinness, and size. They are named lacrimal because they contain part of the canal through which the tear duct runs.

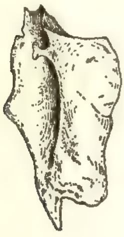


FIG. 40. — LACRIMAL BONE.

Zygomatic or malar bones. — They form the prominence of the cheeks and part of the outer wall and floor of the orbits. A long, narrow, and serrated process, called the temporal process, of each malar bone projects backward and articulates with the zygomatic process of the temporal bone, thus forming the zygomatic arch of each side.

Palatine bones. — Each one is shaped somewhat like an "L" and consists of a horizontal part, a vertical part, and three processes, *viz.:* the pyramidal, orbital, and sphenoidal processes. They are situated at the back part of the nasal cavity between the maxillæ and the pterygoid processes of the sphenoid and help to form (1) the back part of the roof of the mouth, (2) part of the floor and outer wall of the nasal cavities, (3) a very small portion of the floor of the orbit.

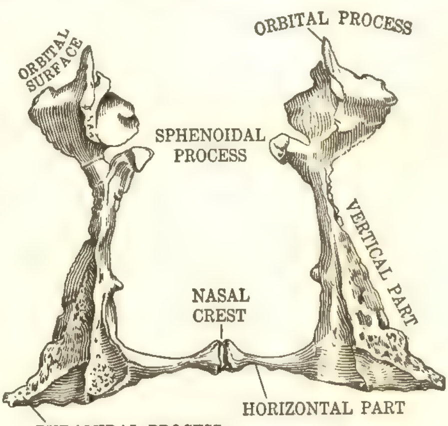


FIG. 41. — THE TWO PALATINE BONES IN THEIR NATURAL POSITION. Viewed from behind. (Gerrish.)

Maxillæ, or upper jaw bones, also known as superior maxillary bones. — The maxillæ are two in number, right and left, and form by their union the whole of the upper jaw. Each bone assists in forming (1) part of the floor of the orbit, (2) the floor and lateral wall of the nasal cavities, (3) the greater part of the roof of the mouth.

Each consists of a body and four processes. The body of the bone contains a large cavity known as the *antrum of Highmore,* which opens into the nose. Three processes, the frontal, zygomatic and alveolar, are shown on Fig. 42. The alveolar process is exca-

vated into cavities varying in depth and size according to the teeth they contain. The palatine process (which does not show on illustration) projects medialward from the nasal surface of the bone and forms part of the floor of the nose and the roof of the mouth. Before birth these bones usually unite to form one bone. When they fail to do so, we have the condition known as cleft palate.[9]

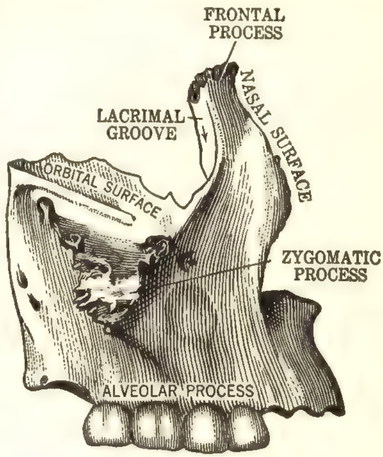


FIG. 42. — THE RIGHT MAXILLA. Outer surface. (Gerrish.)

Mandible, or lower jaw-bone, also known as inferior maxillary bone. — It is the largest and strongest bone of the face and consists of a curved horizontal portion, the body, and two perpendicular portions, the rami. The superior or alveolar border of the body is hollowed out into cavities for the reception of the teeth. Each ramus has a condyle which articulates with the mandibular fossa of the temporal bone and a coronoid process which gives attachment to the temporal muscle and some of the fibers of the buccinator. The deep depression between these two processes is called the mandibular notch. The mental foramen, which is just below the first molar tooth, serves as a passageway for the inferior dental nerve, which is a terminal branch of the mandibular nerve, which in turn is a branch of the fifth or trigeminal nerve. Branches of the inferior

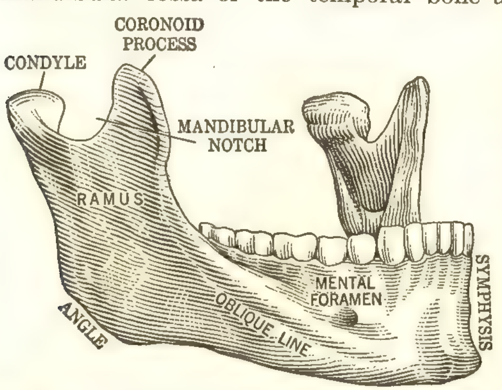


FIG. 43. — THE MANDIBLE. Viewed from the right and a little in front. (Gerrish.)

[9] In its most elementary form cleft palate is a divided uvula. In a more severe form the cleft extends through the soft palate, and the posterior part of the hard palate may be involved. In the severest forms the cleft extends through the alveolus between the teeth. It may affect one or both sides and may be complicated with a cleft in the lip (hare-lip).

dental nerve supply the molar and premolar teeth of the lower jaw.

At birth, the mandible consists of two parts which join at the symphysis in front and form one bone, usually during the first year. It undergoes several changes in shape during life, due mainly (1) to the first and second dentition, (2) to the loss of teeth in the aged, and (3) the subsequent absorption of that part of the bone which contained them.

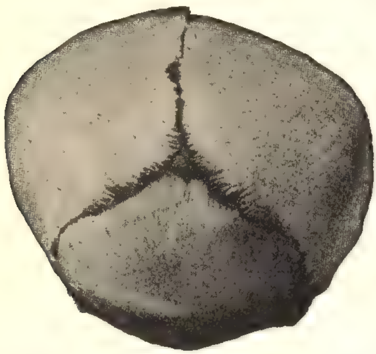


FIG. 44. — SKULL OF NEW-BORN CHILD. To show moulding. (Edgar.)

The skull as a whole. — The cranium is a firm case or covering for the brain. Four[10] of the eight bones which form this bony covering are flat bones, and consist of two layers of compact tissue, the outer one thick and tough, the inner one thinner and more brittle. The base of the skull is much thicker and stronger than the walls and roof; it presents a number of openings for the passage of the cranial nerves, blood-vessels, etc.

The bones of the cranium begin to develop at a very early period of fetal life. Before birth the bones at the top and sides of the skull are separated from each other by membranous tissue in which bone is not yet formed.

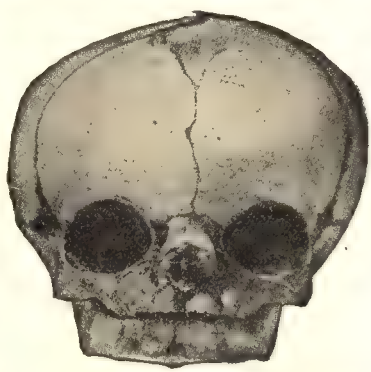


FIG. 45. — SKULL OF NEW-BORN CHILD. To show moulding. (Edgar.)

The fontanels. — The spaces at the angles of the bones occupied by membranous tissue are termed the fontanels, so named from the pulsations of the brain, which can be seen in some of them and which the early anatomists likened to the rise and fall of water in a fountain. There are six of these fontanels.

The *anterior* or *bregmatic fontanel* is the largest, and is a lozenge-shaped space between the angles of the two parietal bones and the

[10] The occipital, two parietals, and the frontal.

two segments of the frontal bone. Normally this fontanel closes at about eighteen months of age.

In abnormal conditions it may close much earlier or much later. In cases of retarded brain growth called microcephalus it closes early. In hydrocephalus the increased pressure may cause it to remain open. In rickets and cretinism which are not yielding to treatment it may not close until much later.

The *posterior fontanel* is much smaller in size, and is a triangular space between the occipital and two parietal bones. Usually this closes by an extension of the ossifying process a few months after birth.

There are two *anterolateral fontanels* at the junction of the frontal, parietal, temporal, and sphenoid bones. They are quite small and usually close by the third month.

There are two *posterolateral fontanels* at the junction of the parietal, occipital, and temporal bones. They decrease in size but usually do not close entirely until the second year.

The membranous tissue between the cranial bones at the sutures and fontanels allows more or less overlapping during labor, thus reducing the diameters of the skull. This is called *moulding* and accounts for the elongated shape of the head of a new-born infant, particularly if the labor has been long.

Sinuses of the head. — Four sinuses communicate with each nasal cavity: the frontal and the ethmoidal, which open into the nasal cavity; the sphenoidal, which opens into the naso-pharynx, and the maxillary or antrum of Highmore, which opens on the lateral wall of each nasal passage. The mucous membrane which lines the nose also lines all of these sinuses, and inflammation of this membrane may extend into any of them and cause *sinusitis*. The mastoid cells are comparable to the sinuses and lined by an extension of the same mucous membrane that lines the sinuses.

At birth the skull is proportionately larger than other parts of the skeleton and the facial portion is small. The small size of the maxillæ and mandible, the non-eruption of the teeth, the small size of the sinuses and nasal cavities account for the smallness of the face. With the eruption of the first teeth there is an enlargement of the face and jaws. This enlargement is much more pronounced after the eruption of the second set of teeth. Usually the skull becomes thinner and lighter in old age, but occasionally the inner table hypertrophies, causing an increase in weight and thickness.[11] The most noticeable feature of the old skull is the decrease in the size of the maxillæ and mandible, resulting from the loss of the teeth and the absorption of the alveolar processes.

Hyoid bone. — This bone is shaped like a horseshoe and consists of a central part called the body and two projections on each side called the greater and lesser cornua. It is suspended from

[11] This condition is called pachycephalia.

the styloid processes of the temporal bones and may be felt in the neck just above the laryngeal prominence (Adam's apple). It

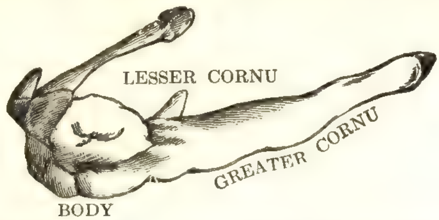


FIG. 46. — THE HYOID BONE. Viewed from the left and in front. (Gerrish.)

supports the tongue, and gives attachment to some of its numerous muscles.

THE TRUNK

The bones which enter into the formation of the **trunk** consist of the **vertebræ, sternum,** and **ribs.**

The vertebral column. — It is formed of a series of bones called vertebræ, and in a man of average height is about 71 cm. long (28 in.). In youth the vertebræ are thirty-three in number, and according to the position they occupy are named:

Cervical, in the neck	7	True or movable vertebræ.
Thoracic or dorsal, in the thorax	12	
Lumbar, in the loins	5	
Sacral, in the pelvis	5	False or fixed vertebræ.
Coccygeal, in the pelvis	4	

In the three upper portions of the spine the vertebræ are separate and movable throughout the whole of life, and are known as *true* vertebræ. Those found in the sacral and coccygeal regions are firmly united in the adult, so that they form two bones, five entering into the upper bone or sacrum, and four into the terminal bone or coccyx. These are known as *false* vertebræ, and on account of their union the number of vertebræ in the adult is twenty-six.

The vertebræ. — The vertebræ differ in size and shape but in general their structure is similar. Seen from above, as in Fig. 48, they consist of a body from which two short, thick processes, called the pedicles, project backward, one on each side, to join with the laminæ which unite posteriorly and form the vertebral or neural arch. This arch encloses the spinal foramen. Each vertebra has seven processes: four articular, two to connect with bone above, two to connect with bone below; two transverse, one at each side where the pedicle and lamina join, and one spinous process, projecting backward from the junction of the laminæ.

Cervical vertebræ. — In the cervical region of the vertebral column the bodies of the vertebræ are smaller than in the thoracic, but the arches are larger. The spinous processes are short, and

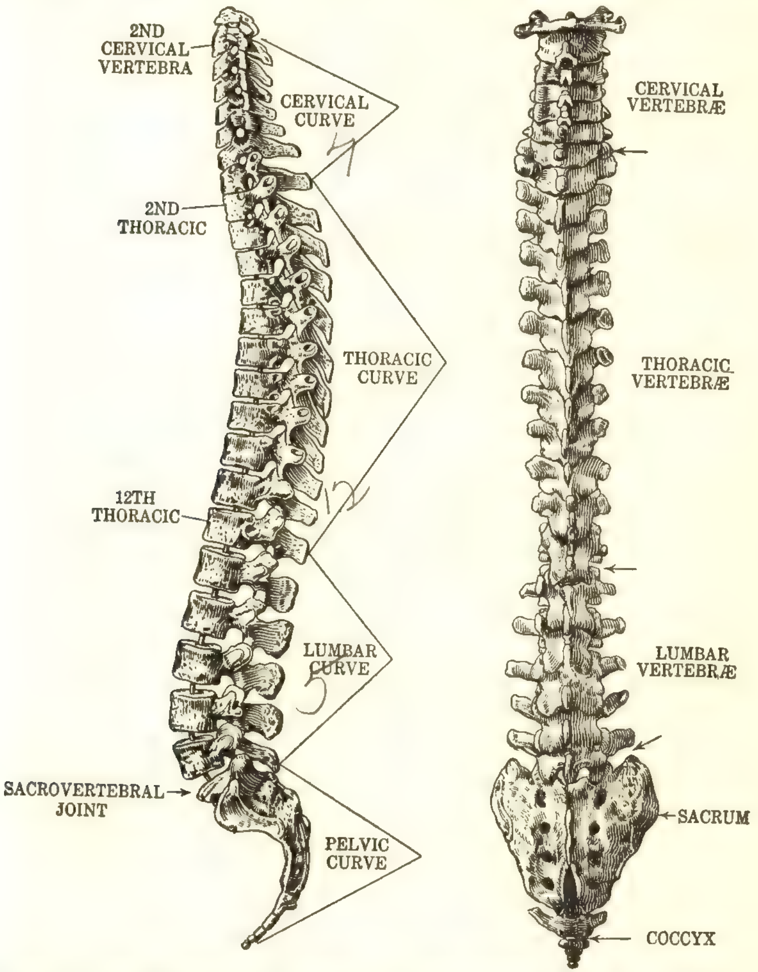


FIG. 47. — THE VERTEBRAL COLUMN. *A*, Right lateral view showing curves; *B*, Dorsal view.

are often cleft in two, or bifid. Each transverse process is pierced by a foramen through which a vertebral artery passes.

The first and second cervical vertebræ differ considerably from the rest. The first, or *atlas*, so named from supporting the head, has practically no body, and may be described as a bony ring consisting of an anterior and posterior arch and two lateral masses.

The latter are bulky and solid. Each has a superior and inferior articular surface. Each superior surface forms a cup for the corresponding condyle of the occipital bone and thus makes possible the backward and forward movements of the head. The bony ring is divided into an anterior and posterior section by a transverse ligament. The posterior section of this ring contains the spinal cord, and the anterior or front section contains the bony projection which arises from the upper surface of the body of the second cervical vertebra, the epistropheus (*axis*). This bony projection, called the *odontoid* process, forms a pivot, and around this pivot the atlas rotates when the head is turned from side to side, carrying the skull, to which it is firmly articulated, with it.

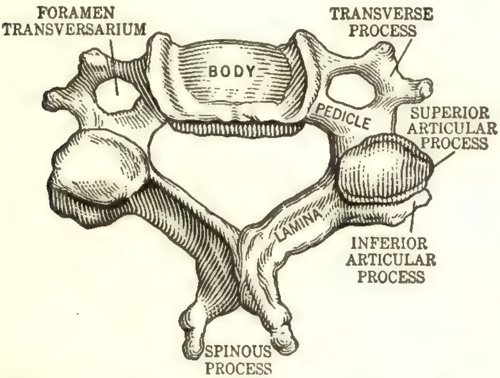


FIG. 48. — A CERVICAL VERTEBRA. Viewed from above.

Thoracic or dorsal vertebræ. — The bodies of the thoracic vertebræ are larger and stronger than those of the cervical; and have a facet or demi-facet for articulation with the heads of the ribs. The transverse processes are longer and heavier than the cervical and all except those of the eleventh and twelfth vertebræ have facets for articulation with the tubercles of the ribs. The spinous processes are long and are directed downward.

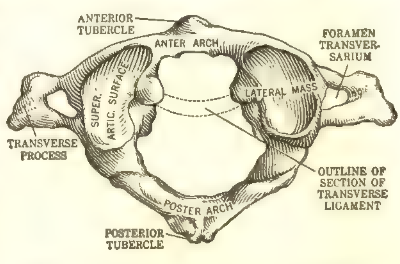


FIG. 49. — THE ATLAS, OR FIRST CERVICAL VERTEBRA.

Lumbar vertebræ. — The bodies of the lumbar vertebræ are the largest and heaviest in the whole spine. The processes are short, heavy, and thick.

Structure of vertebral column. — The bodies of the vertebræ, which are piled one upon another, form a strong, flexible column for the support of the cranium and trunk, provide articular surfaces

for the attachment of the ribs, and the arches form a hollow cylinder behind for the protection of the spinal cord. Viewed from the side, it presents four curves which are alternately convex and concave. The two concave ones, named thoracic and pelvic, are called primary curves because they exist in fetal life and are designed for the accommodation of viscera. The two convex ones, named cervical and lumbar, are called secondary or compensatory curves because they are developed after birth: the cervical when the child is able to hold up his head (at about three or four months) and to sit upright (at about nine months); the lumbar when the child begins to walk (from twelve to eighteen months).

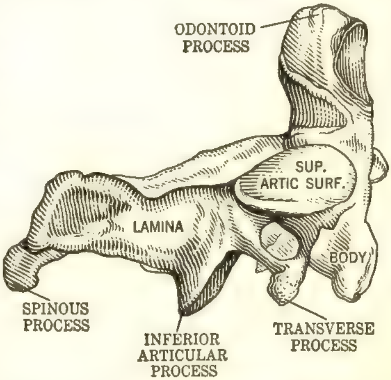


FIG. 50. — THE EPISTROPHEUS OR AXIS. Seen from the right side.

The joints between the bodies of the vertebræ are slightly movable and those between the arches are freely movable. The *bodies* are connected (1) by discs of fibrocartilage placed between each two vertebræ, (2) by the anterior longitudinal ligament which extends along the anterior surfaces of the bodies of the vertebræ from the axis to the sacrum, and (3) by the posterior longitudinal ligament which is inside the vertebral canal and extends along the posterior surfaces of the bodies from the axis to the sacrum.

The *laminæ* are connected by broad, thin ligaments called the *ligamenta flava* (*ligamenta subflava*).

The *spinous processes* are connected at the apices by the supraspinal ligament which extends from the seventh cervical to the sacrum. It is continued upward as the *ligamentum nuchæ*, which extends from the protuberance of the occiput to the spinous process of the seventh cervical vertebra. In some of the lower animals the ligamentum nuchæ serves to sustain the weight of the head but in man it is rudimentary.

Adjacent spinous processes are connected by interspinal ligaments which extend from the root to the apex of each process and meet the ligamenta flava in front and the supraspinal ligament behind. The *transverse processes* are connected by the intertransverse ligaments which are placed between them. The spinal curves confer a considerable amount of springiness and strength upon the

spinal column, and the elasticity is further increased by the ligamenta flava and the discs of fibrocartilage. These discs or pads also mitigate the effects of concussion arising from falls or blows. The vertebral column is freely movable, being capable of bending forward freely, backward and from side to side less freely.[12] In the cervical and thoracic regions a limited amount of rotation is possible.

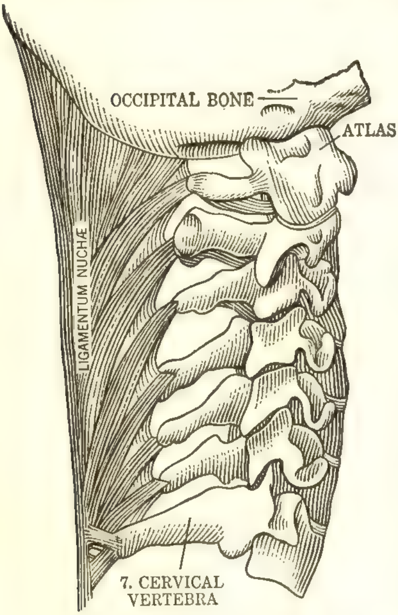


FIG. 51. — THE LIGAMENTUM NUCHÆ. Seen from the right side. (Henle.)

Normal and abnormal conditions. — The weight of the body should rest evenly on the two hip joints, the sternum should project farthest forward, the lower abdomen should be retracted, and the curves of the spinal column should be normal. A perpendicular dropped from the ear should fall through shoulder, hip, and ankle. In this position the chest is up, the head erect, the lower abdominal muscles are retracted, and the body is well balanced and functioning efficiently. As a result of postural habits,[13] injury, or disease the normal curves may become exaggerated and are then spoken of as *curvatures.* If the thoracic curve is exaggerated, it is called *kyphosis* or humpback; if the exaggeration is in the lumbar region, it is called *lordosis* or hollow back. If the curvature is lateral, *i.e.*, toward one side, it is called *scoliosis.* Lateral curvature is usually to the right side, because even in normal people there is often a slight curve toward the right in the thoracic region.

It occasionally happens that the laminæ of a vertebra do not unite and a cleft is left in the arch. This condition is called *spina bifida.* As a result the membranes and the spinal cord itself may protrude, forming a tumor on the child's back. This most often occurs in the lumbosacral region, though it may occur in the thoracic or cervical regions.

Sacrum. — The sacrum is formed by the union of the five sacral vertebræ. It is a large triangular bone situated like a wedge between the coxal bones, and is curved upon itself in such a way as to give increased capacity to the pelvic cavity.

[12] Certain exercises increase the flexibility of the spine to a marked degree.

[13] See publications Nos. 164 and 165 of the Children's Bureau of the U. S. Department of Labor.

Coccyx. — The coccyx is usually formed of four small segments of bone, and is the most rudimentary part of the vertebral column.

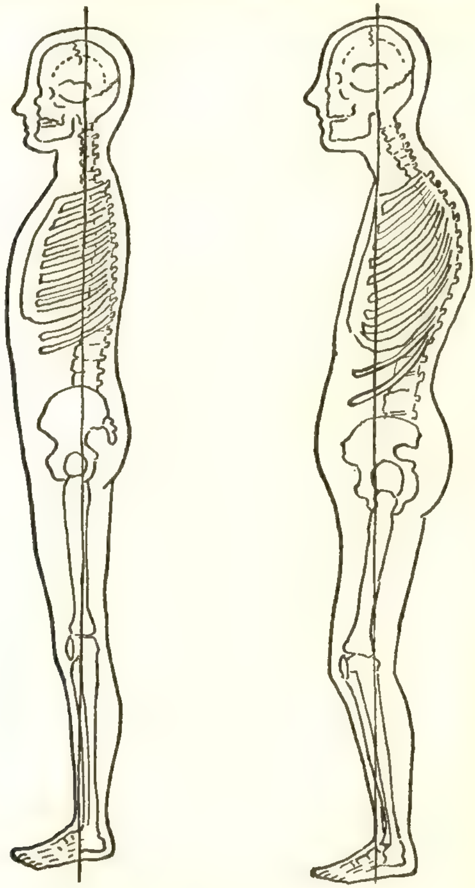


FIG. 52. — *A*, SKELETAL FORM OF A PERSON WITH GOOD BODY MECHANICS. *B*, SKELETAL FORM OF A PERSON WITH POOR BODY MECHANICS. (Courtesy, Children's Bureau, U. S. Department of Labor.)

THORAX

The thorax is a bony cage formed by the sternum and costal cartilages in front, the ribs on each side, and the bodies of the thoracic vertebræ behind. It is cone-shaped, being narrow above and broad below, flattened from before backward and shorter in front than in the back. In infancy the chest is rounded, the width from shoulder to shoulder and the depth from the sternum to the

vertebræ are about equal. As growth progresses the width increases out of proportion to the depth. The thorax supports the bones of the shoulder girdle and upper extremities, and contains and protects the principal organs of respiration and circulation.

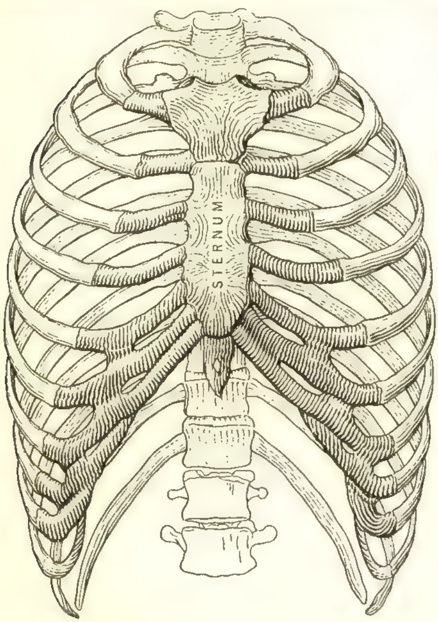


FIG. 53. — BONES OF THE THORAX. Seen from the front.

Sternum or breast bone. — It is a flat, narrow bone about six inches long, situated in the median line in the front of the chest. It develops as three separate parts. The upper part is named the manubrium; the middle and largest part is named the body, or gladiolus; the lowest portion is termed the ensiform, or xiphoid process. On both sides of the manubrium and body are notches for the reception of the sternal ends of the upper seven costal cartilages. The xiphoid process has no ribs attached to it, but affords attachment for some of the abdominal muscles.

At birth the sternum consists of several unossified portions, the body alone developing from four centers. Union of the centers in the body begins at about puberty and proceeds from below upward until at about twenty-five years of age they are all united. The xiphoid process sometimes becomes joined to the body by thirty years of age, more often after forty. In advanced life the manubrium may become joined to the body by bony tissue. Posture and dietary hygiene have much to do with shaping the sternum and the thoracic cavity.

Ribs (costæ). — The ribs, twenty-four in number, are situated twelve on each side of the thoracic cavity. They are elastic arches of bone consisting of a body or shaft and two extremities, the posterior or vertebral and the anterior or sternal. Each rib is connected with the thoracic vertebra by the head and tubercle of the posterior extremity. The head fits into a facet [14] formed on the

[14] The heads of the first, tenth, eleventh, and twelfth ribs each articulate with a single vertebra. The heads of the remaining ribs articulate with facets formed by the bodies of two adjacent vertebræ.

body of one vertebra, or formed by the adjacent bodies of two vertebræ; the tubercle [15] articulates with the transverse processes. Strong ligaments surround and bind these articulations but permit slight gliding movements.

The anterior extremities of each of the first seven pairs are connected with the sternum in front by means of the costal cartilages. They are called *true ribs*. The remaining five pairs are termed *false ribs*. Of these, the upper three, eighth, ninth, and tenth, are attached in front to the costal cartilages of the next rib above. The two lowest are unattached in front, and are termed *floating ribs*.

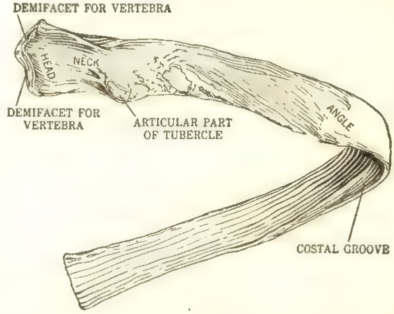


FIG. 54. — A CENTRAL RIB OF THE RIGHT SIDE. Viewed from behind.

The convexity of the ribs is turned outward so as to give roundness to the sides of the chest and increase the size of its cavity; each rib slopes downward from its posterior attachment, so that its sternal end is considerably lower than its vertebral. The lower border of each rib is grooved for the accommodation of the intercostal nerves and blood-vessels. The spaces left between the ribs are called the intercostal spaces.

THE EXTREMITIES

The appendicular skeleton consists of the appendages of the skeleton, namely, the upper and lower extremities.

BONES OF THE UPPER EXTREMITIES

Shoulder Girdle	Clavicle, clavicula, or collar bone	2	64
	Scapula, shoulder blade	2	
Humerus, arm bone		2	
Ulna, elbow bone		2	
Radius, small bone of forearm		2	
Carpus, wrist (ossa carpi)		16	
Metacarpus, body of hand		10	
Phalanges, 2 in thumb, 3 in each finger		28	

The two clavicles and the two scapulæ form the *shoulder girdle*, which is incomplete in front and behind. The clavicles articulate with the sternum in front but behind the scapulæ are connected to

[15] In the eleventh and twelfth ribs the articulation between the tubercle and the adjacent transverse process is missing.

the trunk by muscles only. The shoulder girdle serves to attach the bones of the upper extremity to the axial skeleton.

FIG. 55. — THE RIGHT CLAVICLE. Upper surface. (Gerrish.)

Clavicle or collar bone. — It is a long bone with a double curvature, which is placed horizontally at the upper and anterior part of the thorax, just above the first rib. It articulates with the sternum by its inner extremity, which is called the sternal extremity. Its outer or acromial extremity articulates with the scapula.

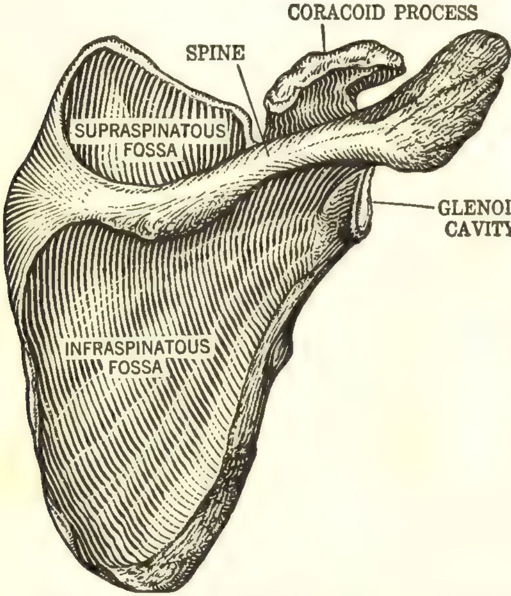


FIG. 56. — THE RIGHT SCAPULA, OR SHOULDER BLADE.
Dorsal surface.

In the female, the clavicle is generally less curved, smoother, shorter, and more slender than in the male. In those persons who perform considerable manual labor, which brings the muscles con-

nected with this bone into constant action, it acquires considerable bulk.

Scapula or shoulder blade. — It is a large, flat bone triangular in shape, placed between the second and seventh ribs on the back part of the thorax. It is unevenly divided on its dorsal surface by a very prominent ridge, the spine of the scapula, which terminates in a large triangular projection called the *acromion process* which articulates with the clavicle. Below the acromion process, at the head of the shoulder blade, is a shallow socket, the *glenoid cavity*, which receives the head of the humerus.

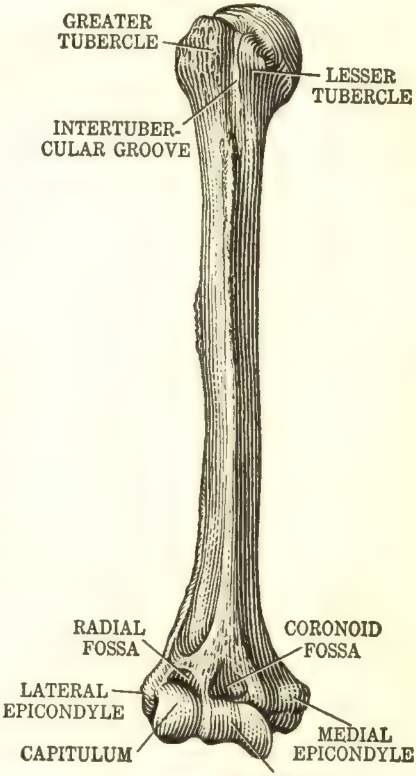


FIG. 57. — THE RIGHT HUMERUS, OR ARM BONE. Ventral view.

Humerus or upper arm[16] bone. — The humerus is the longest and largest bone of the upper limb. The upper extremity consists of a rounded head joined to the shaft by a constricted neck and of two eminences called the greater and lesser tubercles, between which is the intertubercular[17] groove. The constricted neck above the tubercles is called the anatomical neck, and that below the tubercles, the surgical neck, because it is so often fractured. The head articulates with the glenoid cavity of the scapula. The lower extremity of the bone is flattened from before backward and ends below in an articular surface which is divided by a ridge into a lateral eminence called the capitulum and a medial portion called the trochlea. The capitulum is rounded and articulates with the depression on the head of the radius. The trochlea articulates with

[16] Anatomically the word arm is reserved for that part of the upper limb which is above the elbow; between the elbow and wrist is the forearm; below the wrist are the hand and fingers.

[17] Also called bicipital groove.

the ulna. Above these surfaces on the lateral and medial aspects are projections called epicondyles.

Ulna or elbow bone. — It is the large bone of the forearm and is placed at the medial side (little finger side) parallel with the radius. Its upper extremity presents two curved processes and two concave cavities; the larger process forms the prominence of the elbow, and is called the olecranon process. The smaller process is called the coronoid, and the trochlea of the humerus fits into the cavity — the semilunar notch or greater sigmoid cavity — between these two processes. The radial notch or lesser sigmoid cavity is on the lateral side of the coronoid, and articulates with the head of the radius. The lower extremity of the ulna is of small size and ends in two eminences; the larger one, called the head, articulates with the disc of fibrocartilage which separates it from the wrist; the smaller one, called the styloid process, serves for the attachment of a ligament from the wrist joint.

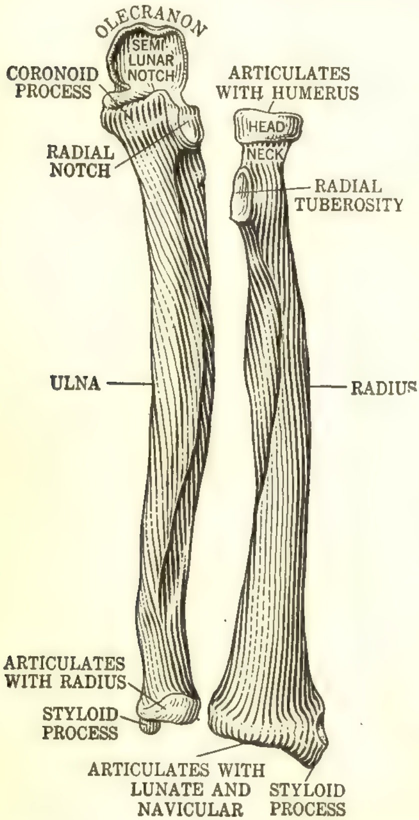


FIG. 58. — ANTERIOR VIEW OF THE BONES OF THE LEFT FOREARM.

Radius. — The radius is placed on the lateral side of the ulna and is shorter and smaller than the ulna. The upper extremity presents a head, a neck, and a tuberosity. The head is small and rounded and has a shallow cup-like depression on its upper surface for articulation with the capitulum of the humerus. A prominent ridge surrounds the head and by means of this it rotates within the radial notch of the ulna. The head is supported on a constricted portion called the neck. Beneath the neck on the medial side is an eminence called the radial tuberosity into which the tendon of the biceps brachii muscle is

inserted. The lower extremity has two articular surfaces, one below, by which it articulates with the navicular and lunate bones of the wrist, and the other at the medial side called the ulnar notch, by which it articulates with the ulna. Fracture of the lower third of the radius is called Colles' fracture.[18]

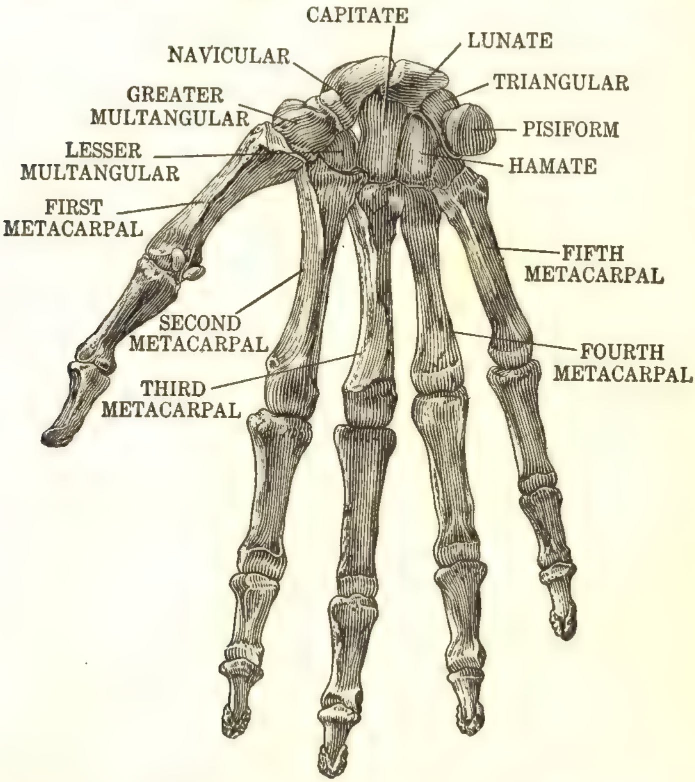


FIG. 59. — THE BONES OF THE RIGHT HAND. Volar surface.

Carpus or wrist. — The wrist joint is composed of eight small bones (ossa carpi), united by ligaments; they are arranged in two rows, and are closely joined together, yet by the arrangement of their ligaments allow a certain amount of motion. They afford origin by their palmar surface to most of the short muscles of the thumb and little finger, and are named as follows:

Proximate or upper row		Distal or lower row		
1. Navicular (scaphoid)....	1	5. Greater multangular (trapezium)	1	8
2. Lunate (semilunar)......	1	6. Lesser multangular (trapezoid)..	1	
3. Triangular (cuneiform)..	1	7. Capitate (os magnum).........	1	
4. Pisiform..............	1	8. Hamate (unciform)............	1	

[18] Abraham Colles, Irish surgeon, 1773–1843.

Metacarpus or body of hand. — Each metacarpus is formed by five bones (ossa metacarpalia), numbered from the lateral side. The bones are curved longitudinally, being convex behind and concave in front. They articulate at their bases with the second row of carpal bones and with each other. The heads of the bones articulate with the bases of the first row of the phalanges.

Phalanges. — These are the bones of the fingers, and are fourteen in number in each hand, three for each finger and two for the thumb. The first row articulates with the metacarpal bones and the second row of phalanges; the second row, with the first and third; and the third, with the second row.

BONES OF THE LOWER EXTREMITIES

Hip bones, ossa coxæ or ossa innominata	2	62
Femur, thigh bone	2	
Patella, knee-cap	2	
Tibia, shin bone, 2; Fibula, small bone of calf, 2 } leg	4	
Tarsus, ossa tarsi	14	
Metatarsus, sole and lower instep	10	
Phalanges, 2 in great toe, 3 in others	28	

The two hip bones which articulate with each other in front form the *pelvic girdle.* The upper part of the sacrum fills in the gap behind. These three bones form a rigid and complete ring. The pelvic girdle serves to attach the lower extremities to the axial skeleton.

The bones of the lower extremities correspond in general with those of the upper extremities, and bear a rough resemblance to them, but their function is different. The lower limbs support the body in the erect position and are therefore more solidly built, and their parts are less movable than the corresponding parts of the upper limbs.

Hip bone, os coxæ, or os innominatum.[19] — It is a large, irregularly shaped bone which, with its fellow of the opposite side, forms the sides and front wall of the pelvic cavity. In youth it consists of three separate parts. In the adult these have become united, but it is usual to describe the bone as divisible into three portions: (1) the ilium (plural *ilia*), (2) the ischium (plural *ischia*), (3) the pubis (plural *pubes*).

The **ilium** is the upper broad and expanded portion which forms the prominence of the hip. The **ischium** is the lower and strongest

[19] Os innominatum or "unnamed bone," so called because it did not resemble any known object.

portion of the bone, while the **pubis** is that portion which helps to form the front of the pelvis. Where these three portions of the bone meet and finally ankylose is a deep socket, called the *acetabulum* (cotyloid cavity), into which the head of the femur fits. Other points of special interest to note in the hip bones are:

(1) The processes formed by the projection of the crest of the ilium in front are called the anterior superior iliac spine and the anterior inferior iliac spine. The former is a convenient landmark in making anatomical and surgical measurements.

(2) The largest foramen in the skeleton, known as the *obturator foramen*, is situated between the ischium and pubis.

(3) The articulation formed by the two pubic bones in front is called the *symphysis pubis*. It serves as a convenient landmark in making measurements.

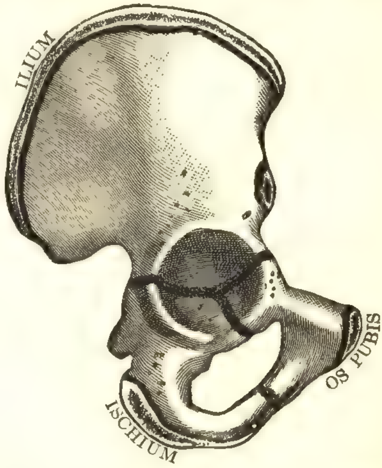


FIG. 60. — DEVELOPMENT OF THE HIP BONE. Showing the union of ileum, ischium, and os pubis in the acetabulum (cotyloid cavity). (Gerrish.)

The pelvis. — The pelvis, so called from its resemblance to a basin, is stronger and more massively constructed than either the cranial or the thoracic cavity. It is composed of four bones, the two hip bones forming the sides and front, the sacrum and coccyx completing it behind. It is divided by a narrowed bony ring into the greater or false, and the lesser or true pelvis. The narrowed bony ring which is the dividing line is spoken of as the *brim of the pelvis.*

The *greater pelvis* is the expanded portion situated above the brim, bounded on either side by the ilium; the front is filled in by the walls of the abdomen. The lesser pelvis is below and behind the pelvic brim, bounded on the front and sides by the pubes and ischia and behind by the sacrum and coccyx. It is described as consisting of an inlet, an outlet, and a cavity. The space included within the brim of the pelvis is called the superior aperture or inlet, and the space below, between the tip of the coccyx behind and the tuberosities of the ischia on either side, is called the inferior aperture or outlet. The cavity of the lesser pelvis is a short curved canal,

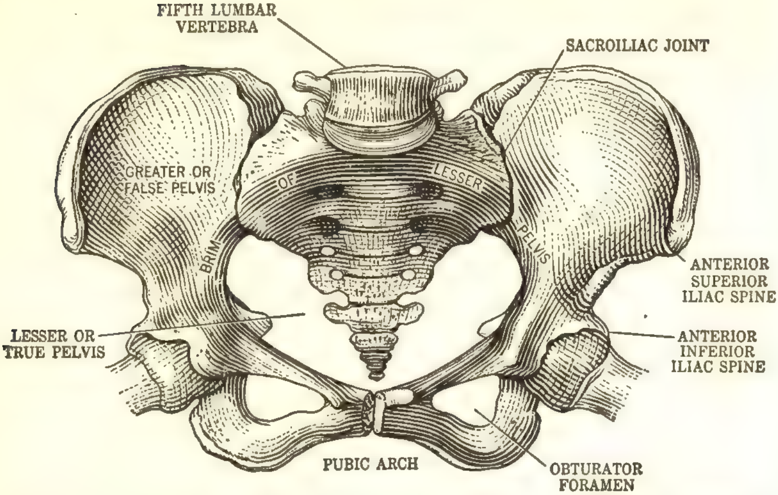


FIG. 61. — THE FEMALE PELVIS. Ventral view. The disc of fibrocartilage which unites the pubic bones is not shown in order that the end of the coccyx may be seen.

deeper on the posterior than on its anterior wall. In the adult it contains part of the sigmoid colon,[20] the rectum, bladder, and some of the reproductive organs. The bladder is behind the sym-

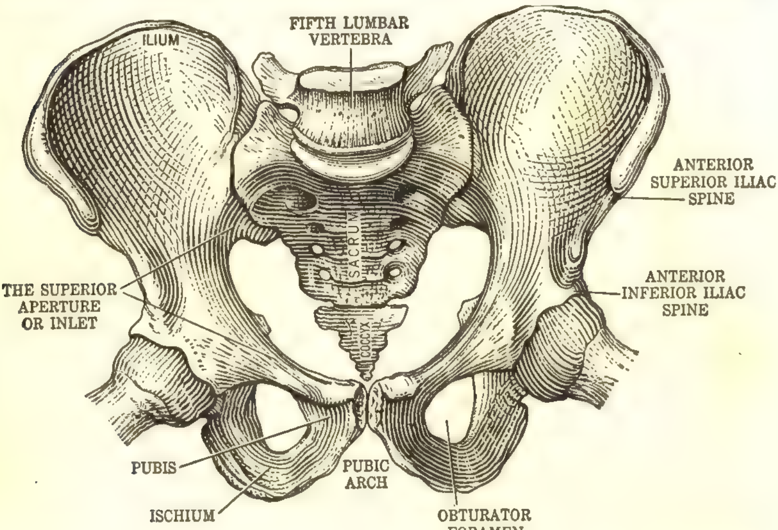


FIG. 62. — THE MALE PELVIS. Ventral view. The disc of fibrocartilage which unites the pubic bones is not shown in order that the end of the coccyx may be seen.

[20] The sigmoid colon is freely movable and may be displaced into the abdominal cavity.

physis of the pubic bones, the rectum is in the curve of the sacrum and coccyx. In the female the uterus, tubes, ovaries, and vagina are between the bladder and the rectum.

The female pelvis differs from that of the male in those particulars which render it better adapted to pregnancy and parturition. It is more shallow than the male pelvis, but wider in every direction. The inlet and outlet are larger, the bones are lighter and smoother, and the coccyx is more movable. As can be seen by reference to Fig. 61 and Fig. 62, a distinctive anatomical difference is that the sub-pubic angle in a male is less than a right angle, and in the female it is greater than a right angle.

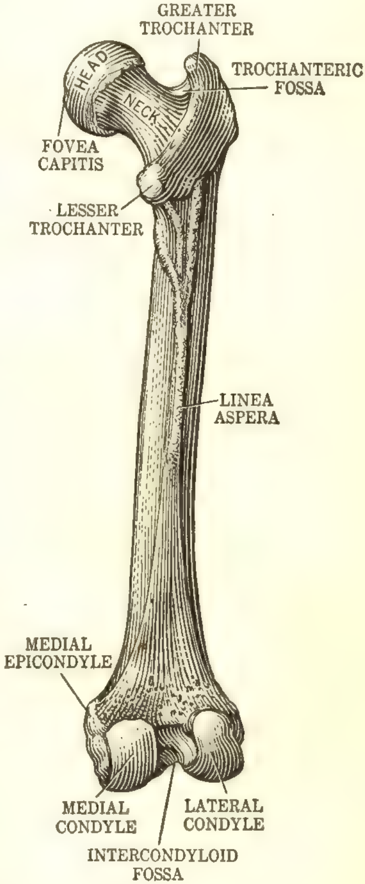


FIG. 63. — THE RIGHT FEMUR, OR THIGH BONE. Dorsal aspect.

Femur or thigh bone. — This is the longest and strongest bone in the skeleton. The upper extremity of the femur consists of a rounded head joined to the shaft by a constricted neck, and of two eminences, called the greater and lesser *trochanters*. The head articulates with the cavity in the hip bone, called the acetabulum. The lower extremity of the femur is larger than the upper, is flattened from before backwards, and divided into two large eminences or *condyles* by an intervening notch. The condyles are called respectively lateral and medial and the intervening notch is called the intercondyloid fossa. The lower end of the femur articulates with the tibia and the patella, or knee-cap. In the erect position it is not vertical, being separated from its fellow by a considerable interval, which corresponds to the entire breadth of the pelvis. The bone inclines gradually downward and inward, so as to approach its fellow towards its lower part, in order to bring the knee-joint near

the line of gravity of the body. The degree of inclination varies in different persons, and is greater in the female than the male, on account of the greater breadth of the pelvis.

Patella or knee-cap. — The patella is a sesamoid bone developed in the tendon of the quadriceps femoris muscle. It is small, flat, triangular in shape, and placed in front of the knee-joint, which it serves to protect. (See Fig. 32.) It articulates with the two condyles of the femur. This articulation is surrounded by many large bursæ.

FIG. 64. — THE RIGHT PATELLA. Ventral surface. (Gerrish.)

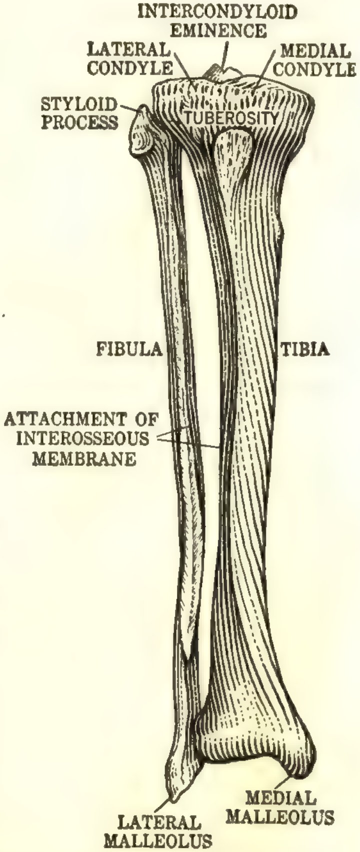


FIG. 65. — THE BONES OF THE RIGHT LEG. Ventral surface.

Tibia or shin bone. — The tibia is situated at the front and medial side of the leg.[21] The upper extremity is large, and expanded into two lateral eminences with a sharp projection — the intercondyloid eminence — between them, nearer the posterior aspect of the bone. The lateral eminences are called respectively medial and lateral condyles. The superior surfaces are concave and receive the condyles of the femur. The lower extremity is much smaller than the upper; it is prolonged downward on its medial side into a strong process, the *medial malleolus*, which forms the inner prominence of the ankle. At the same

[21] Generally speaking, the lower extremity is called the leg. Anatomically the word leg is reserved for that part of the lower extremity between the knee and the ankle. Above the knee is the thigh. Below the ankle are the foot and toes.

lower extremity is the surface for articulation with the talus which forms the ankle joint. The tibia also articulates with the lower end of the fibula. (In the male, the direction of the tibia is vertical and parallel with the bone of the opposite side; but in the female it has a slightly oblique direction lateralward, to compensate for the oblique direction of the femur medialward.)

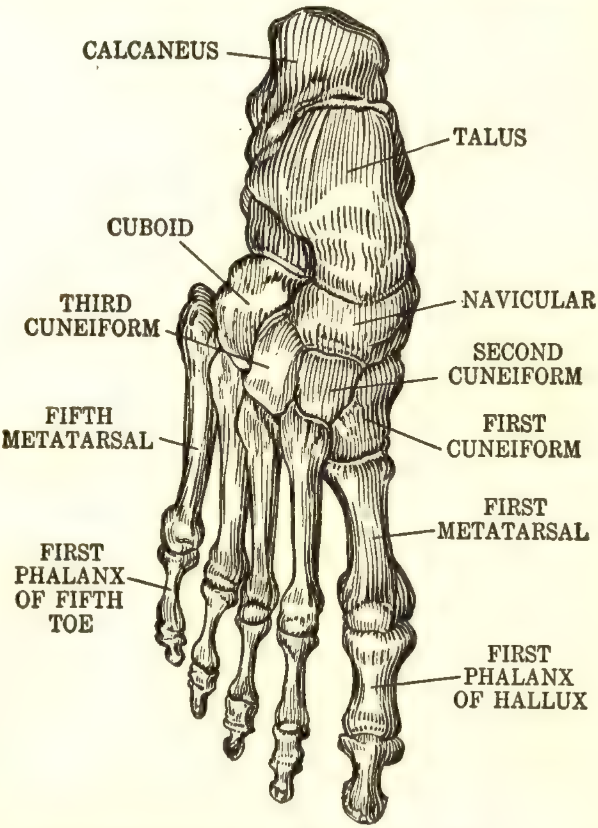


FIG. 66. — THE BONES OF THE RIGHT FOOT. Viewed from above. (Gerrish.)

Fibula or calf bone. — It is situated on the lateral side of the tibia, parallel with it. It is smaller than the tibia and in proportion to its length is the most slender of all the long bones. The upper extremity consists of an irregular quadrate head by means of which it articulates with the tibia, but it is excluded from the knee joint. The lower extremity is prolonged downward into a pointed process, the *lateral malleolus*, which lies just beneath the skin and forms the outer ankle bone. The lower extremity articulates with the tibia

and the talus. The talus is held between the lateral malleolus of the fibula and the medial malleolus of the tibia. A fracture of the lower end of the fibula with injury of the lower tibial articulation is called a Pott's[22] fracture.

Tarsus. — There are seven tarsal bones, namely, the calcaneus, talus, cuboid, navicular, first, second, and third cuneiforms. They differ from the carpal bones in being larger and more irregularly shaped. The largest and strongest of the tarsal bones is called the **calcaneus** or **heel bone**; it serves to transmit the weight of the body to the ground, and forms a strong lever for the muscles of the calf of the leg.

Metatarsus or sole and instep of foot. — The metatarsus is formed by five bones which closely resemble the metacarpal bones of the hand. Each bone articulates with the tarsal bones by one extremity, and by the other with the first row of phalanges. The tarsal and metatarsal bones are so arranged that they form two distinct arches; the one running from the heel to the toes on the inner (medial) side of the foot is called the *longitudinal arch*, and the other across the foot in the metatarsal region is called the *transverse arch.*

These arches may be broken down and destroyed, a condition known as flat-foot. Flat-foot is usually a pathological condition with white members of the human race, but American negroes are racially flat-footed.

Phalanges. — Both in number and general arrangement they resemble those in the hand, there being two in the great toe and three in each of the other toes.

SUMMARY

Bones
- Function
  1. Organs of support.
  2. Instruments of locomotion.
  3. Framework of hard material.
  4. Afford attachment to soft parts.
  5. Shelter delicate structures.
  6. Shape to whole body.
- Classification
  1. Long.
  2. Short.
  3. Flat.
  4. Irregular.

[22] Percival Pott, English surgeon, 1714–1788.

TABLE OF THE BONES

HEAD

Cranium		Face	
Occipital	1	Nasal	2
Parietal	2	Vomer	1
Frontal	1	Inferior nasal concha (Inferior turbinated)	2
Temporal	2	Lacrimal	2
Sphenoid	1	Zygomatic (Malar)	2
Ethmoid	1	Palatine (Palate)	2
	8	Maxilla	2
		Mandible	1
			14

Ear	Malleus	2
	Incus	2
	Stapes	2
		6
	Hyoid bone in the neck	1

TRUNK

		Child	Adult
Vertebræ	Cervical	7	7
	Thoracic	12	12
	Lumbar	5	5
	Sacral	5	1
	Coccygeal	4 = 33	1 = 26
	Ribs		24
	Sternum		1
			51

Upper Extremity		Lower Extremity	
Clavicle	1	Hip bone (os coxæ)	1
Scapula	1	Femur	1
Humerus	1	Patella	1
Ulna	1	Tibia	1
Radius	1	Fibula	1
Carpus		**Tarsus**	
Navicular (Scaphoid)	1	Calcaneus (Calcaneum)	1
Lunate (Semilunar)	1	Talus (Astragalus)	1
Triangular (Cuneiform)	1	Cuboid	1
Pisiform	1	Navicular (Scaphoid)	1
Greater multangular (Trapezium)	1	Third cuneiform (External cuneiform)	1
Lesser multangular (Trapezoid)	1	Second cuneiform (Middle cuneiform)	1
Capitate (Os magnum)	1	First cuneiform (Internal cuneiform)	1
Hamate (Unciform)	1		
Metacarpus	5	Metatarsus	5
Phalanges	14	Phalanges	14
	32		31
	32 × 2 = 64		31 × 2 = 62

CHAPTER VI

JOINTS OR ARTICULATIONS

The various bones of which the skeleton consists are connected at different parts of their surfaces, and such connections are called joints or articulations. The articulating surfaces of the bones are sometimes separated by a thin membrane, sometimes by strong strands of connective tissue or fibrocartilage, and in the freely moving joints are completely separated. Strong ligaments extend over the joint or surround it. Tendons of the voluntary muscles extend over the joints, also.

Classification. — Joints are classified according to the amount of movement of which they are capable.

1. Immovable joints or synarthroses.
2. Slightly movable joints or amphiarthroses.
3. Freely movable joints or diarthroses.

In all instances some softer substance, *i.e.*, cartilage or fibrous tissue, is placed between the bones, uniting them or clothing the opposed surfaces.

Immovable joints, or synarthroses. — The bones are connected by fibrous tissue or cartilage. There are four varieties. These are listed in the summary on page 95. The bones of the cranium and the facial bones (with the exception of the lower jaw) have their adjacent surfaces applied in close contact, with only a thin layer of fibrous tissue placed between their margins. In most of the cranial bones union occurs by means of a series of processes and indentations interlocked together, which form jagged lines of union known as **sutures.**

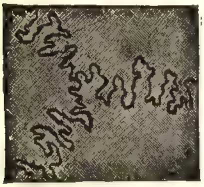


FIG. 67. — A TOOTHED, OR DENTATED, SUTURE.

The three most important sutures are:

(1) *Coronal.* — The line of union between the frontal and parietal bones.

(2) *Lambdoidal.* — The line of union between the parietal and occipital bones.

(3) *Sagittal suture.* — This begins at the base of the nose, extends along the middle line on the top of the crown, separates the frontal

bone into two parts, the parietal bones from each other, and ends at the posterior fontanel. That portion of the sagittal suture which separates the frontal bone into two parts is often called the

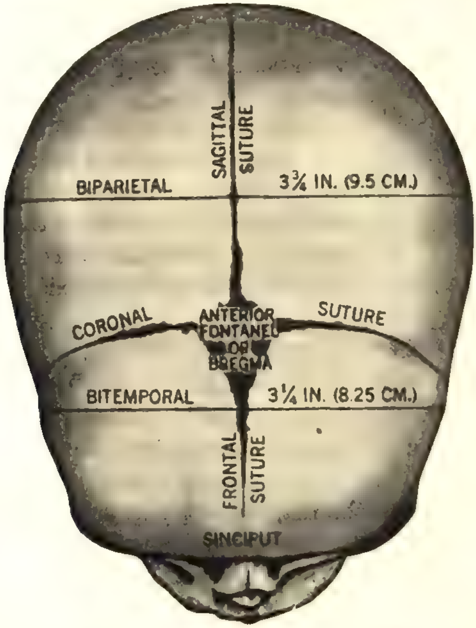


FIG. 68. — DIAMETERS AND LANDMARKS OF THE FETAL SKULL. Upper surface. (Edgar.)

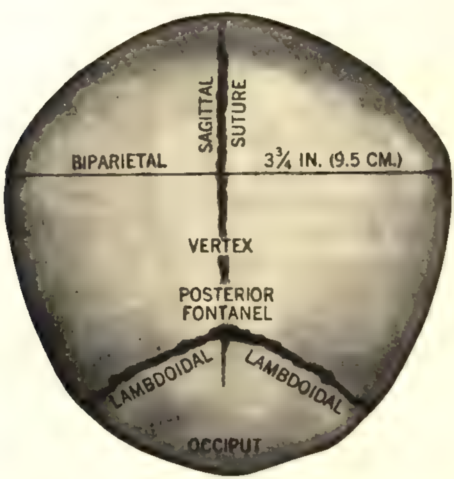


FIG. 69. — DIAMETERS AND LANDMARKS OF THE FETAL SKULL. Posterior surface. (Edgar.)

frontal suture. The junction of the sagittal and coronal sutures is called the *bregma;* the junction of the sagittal and lambdoidal sutures is called the *lambda.*

Slightly movable joints, or amphiarthroses. — These terms are applied to joints that permit of slight movement and include two varieties: (1) symphysis and (2) syndesmosis.

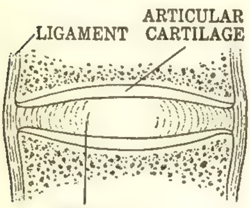


FIG. 70. — DIAGRAM OF A SECTION OF A SYMPHYSIS.

Symphysis. — In this form of articulation the bony surfaces are joined together by broad, flattened discs of fibrocartilage, as in the articulations between the bodies of the vertebræ. These intervertebral discs being compressible and extensile, the spine can be moved to a limited extent in every direction. In the pelvis the articulations between the two pubic bones (symphysis pubis) (see Fig. 61), and between the sacrum and ilia (sacroiliac articulation), are slightly movable. The pubic bones are united by a disc of fibrocartilage and by ligaments. In the sacroiliac articulation the sacrum is united more closely to the ilia, the articular surfaces being covered by cartilage and held together by ligaments.

The fibrocartilage between these joints (symphysis pubis and sacroiliac) becomes thickened and softened during pregnancy and allows of a certain limited motion which is essential to a normal birth.

Syndesmosis. — In this type of articulation the bony surfaces are united by an interosseous ligament, as in the lower tibio-fibular articulation.

Freely movable joints, or diarthroses. — The greater number of joints in the body belong to this class. The adjacent ends of the bones are covered with fibrocartilage and surrounded by a more or less perfect fibrous capsule which is strengthened by ligaments and lined by synovial membrane. (See Fig. 71.)

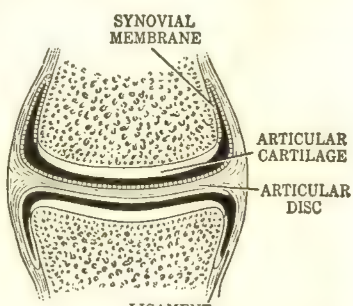


FIG. 71. — DIAGRAM OF A SECTION OF A MOVABLE JOINT WITH AN ARTICULAR DISC OF CARTILAGE.

The varieties of joints in this class have been determined by the kind of motion permitted in each. They are as follows:

(1) *Gliding joints* admit of only gliding movement, as in the joints between the articular processes of

the vertebræ. The articular surfaces are nearly flat, or one may be slightly concave, the other slightly convex.

(2) *Hinge joints* are joints with an angular movement in one direction like a door on its hinges. The articular surfaces are of such shape as to permit motion only in one plane, forward and backward. These movements are called flexion and extension, and may be seen in the joint between the humerus and ulna, in the ankle joint, and in the articulations of the phalanges.

(3) *Condyloid joints* admit of an angular movement in two directions. When an oval-shaped head or condyle of bone is received into an elliptical cavity, it is said to form a condyloid joint, *e.g.*, the wrist (radiocarpal) joint.

(4) *Saddle joints* are similar in function to condyloid joints and admit of an angular movement in two directions. The articular surface of each bone is concave in one direction and convex in another, at right angles to the former. The metacarpal bone of the thumb is articulated with the greater multangular bone of the carpus by a saddle joint.

(5) *Pivot joints* are joints with a rotary movement in one direction. In this form a ring rotates around a pivot, or a pivot-like process rotates within a ring, the ring being formed of bone and cartilage. In the articulation of the axis and atlas, the front of the ring is formed by the anterior arch of the atlas, and the back by the transverse ligament. The odontoid process of the axis forms a pivot and around this pivot the ring rotates, carrying the head with it. In the proximal articulation of the radius and ulna the head of the radius rotates within the ring formed by the radial notch of the ulna and the annular ligament. The hand is attached to the lower end of the radius, and the radius, in rotating, carries the hand with it; thus, the palm of the hand is alternately turned forward and backward. When the palm is turned forward, or upward, the attitude is called supination; when backward, or downward, pronation.

(6) *Ball and socket joints* have an angular movement in all directions and a pivot movement. In this form of joint a more or less rounded head is received into a cup-like cavity, as the head of the femur into the acetabulum, and the head of the humerus into the glenoid cavity of the scapula. The shoulder joint is the most freely movable joint in the body.

Movement. — Bones thus connected are capable of four different kinds of movement which rarely occur singly but usually in combinations which produce great variety.

1. *Gliding movement.* — This is the simplest kind of motion that can take place in a joint, one surface gliding or moving over another without any angular or rotatory movement.

2. *Angular movement.* — This occurs only between long bones, and by it the angle between two bones is either increased or diminished. It includes flexion, extension, abduction, and adduction.

a. Flexion. — A limb is flexed when it is bent, *e.g.*, bending the arm.

b. Extension. — A limb is extended when it is straightened out, *e.g.*, straightening the arm, hence the reverse of flexion.

c. Abduction. — This term means drawn away from the middle line of the body, *e.g.*, lifting the arm away from, or at right angles to the body.

d. Adduction. — This term means brought to, or nearer, the middle line of the body, *e.g.*, bringing the arm to the side of the body.

Both abduction and adduction have a different meaning when used with reference to the fingers and toes. In the hand the imaginary line is supposed to be drawn through the middle finger, and in the foot through the second toe.

3. *Circumduction* means that form of motion which takes place between the head of a bone and its articular cavity, when the bone is made to circumscribe a conical space by rotation around an imaginary axis, *e.g.*, swinging the arms or legs.

4. *Rotation* means a form of movement in which a bone moves around a central axis, often an imaginary one, without undergoing any displacement from this axis, *e.g.*, rotation of the atlas around the odontoid process of the axis.

Complete rotation as of a wheel is not possible in any of the joints of the body for the simple reason that such motion would necessarily tear asunder all the vessels, nerves, muscles, etc.

Ankylosis. — Immobility and consolidation of a joint.

Dislocation. — If in addition to a sprain, the bone is displaced, the injury is called a dislocation.

Sprain. — A wrenching or twisting of a joint accompanied by a stretching or tearing of the ligaments or tendons is called a sprain.

Joints or Articulations — connections existing between bones.

- **Immovable Joint or Synarthrosis** — Bones are connected by fibrous tissue or cartilage
  - *Sutures.* — Articulations by processes and indentations interlocked together.
    - *True Sutures*
      - Sutura dentata — tooth-like, *e.g.*, sutures between parietal bones.
      - Sutura serrata — saw-like, *e.g.*, sutures between two portions of frontal bone.
      - Sutura limbosa — in addition to interlocking the articular surfaces are beveled and overlap, *e.g.*, suture between parietal and frontal bones.
    - *False Sutures*
      - Suture squamosa — scale-like, *e.g.*, sutura between the temporal and parietal bones.
      - Sutura harmonica — simple apposition of rough surfaces, *e.g.*, articulations between the maxillæ.
  - *Schindylesis.* — A thin plate of bone is received in a cleft or fissure of another bone, *e.g.*, the reception of the vomer in the fissure between the maxillæ and between the palatine bones.
  - *Gomphosis.* — A conical process fits into a socket, *e.g.*, roots of teeth into the alveoli of the maxillæ and mandible.
  - *Synchrondrosis.* — Temporary joint. Cartilage between bones ossifies in adult life, *e.g.*, between the occipital and sphenoid.
- **Slightly Movable Joint or Amphiarthrosis** — Bones are connected by discs of cartilage or interosseous ligaments.
  1. *Symphysis.* — The bones are united by a plate or disc of fibrocartilage of considerable thickness.
  2. *Syndesmosis.* — The bony surfaces are united by an interosseous ligament, as in the lower tibio-fibular articulation.
- **Movable Joint or Diarthrosis**
  1. Fibrocartilage covering adjacent ends of the bones.
  2. Fibrous capsule strengthened by ligaments.
  3. Synovial membrane lining fibrous capsule.

  1. *Arthrodia.* — Gliding joint; articulates by surfaces which glide upon each other.
  2. *Ginglymus.* — Hinge or angular joint; moves backward and forward in one plane.
  3. *Condylarthrosis.*—Condyloid joint; ovoid head received into elliptical cavity.
  4. *Reciprocal Reception.* — Saddle joint; articular surfaces are concavo-convex.
  5. *Trochoides.* — Pivot joint; articulates by a process turning within a ring, or by a ring turning around a pivot.
  6. *Enarthrosis.* — Ball-and-socket joint; articulates by a globular head in a cup-like cavity.
- **Movement**
  1. Gliding movement.
  2. Angular. — Flexion. Extension. Abduction. Adduction.
  3. Circumduction.
  4. Rotation.

CHAPTER VII

MUSCULAR TISSUE: CLASSIFICATION; SKELETON MUSCLES

One of the important functions of the human body is *motion.* Under this heading many types of movements are included, namely, the ability to move from place to place, the movements of breathing, the beating of the heart, the contractions of the stomach, intestines, etc. Varied as these movements seem to be they are all brought about by the contractions of muscular tissue.

This tissue arises from the mesoderm, and forms the bulk of all the muscles which are attached to the skeleton, and which by contracting bring about changes in the form and position of nearly all parts of the body. Muscular tissue also is found in the walls of such organs as the stomach and intestines and forms the wall of the heart. Contraction of this tissue decreases the capacity of these organs, while relaxation increases it.

The activities of the muscular system are dependent upon the skeletal and the nervous systems. The skeletal, the muscular, and the nervous systems are correlated parts, the degree of usefulness of any one of them depending on the development and proper functioning of the others.

The appearance of human muscular tissue is roughly comparable to that of lean meat. It constitutes from 40 to 50 per cent of the body weight.

Characteristics. — The special characteristics of muscular tissue are irritability (excitability), contractility, extensibility, and elasticity.

Irritability or *excitability* may be defined as the property of receiving stimuli and responding to them. All cells possess this property; neurons, ciliated epithelial cells, and the cells of muscular tissue in a marked degree. The response of any tissue to stimulation is to perform its special function, and in the case of muscular tissue this response takes the form of contraction.

Contractility is the property which enables muscles to change their shape and become shorter and thicker. This property is characteristic of all protoplasm, but is more highly developed in muscular tissue than in any other.

Extensibility of a living muscle means that it can be stretched or extended, and *elasticity* means that it readily returns to its original form.

Tone. — This term is applied to the mild, sustained contraction of muscular tissue which may vary in degree but is rarely absent altogether.

Muscle cells within a muscle trunk act independently and a muscle cell if it contracts at all is said always to exert its full force. A muscle therefore may contain working and idling cells and in consequence may show any degree of contraction or go slowly and smoothly into greater and greater contractions depending on the number of contracting cells which are working and their rhythm of work. Then, too, if some of the cells are shortening as they contract (isotonic contraction) and some although contracting cannot shorten, but develop tension instead (isometric contraction), the whole muscle will be steadied and put into a state of tone (partial contraction) slowing down and smoothing the contraction of the whole muscle. Some muscles contract more rapidly than others, as in the case of the extensors of the arm, which naturally contract more rapidly than the flexors.

The tone of skeletal muscles gives them a certain firmness and maintains a slight, steady pull upon their attachments; it also functions in the maintenance of posture and in a certain pressure upon the contents of the abdomen. It is important in two ways: (1) smoothness of movement is dependent upon it; (2) a stretched muscle will contract more quickly than one that is relaxed. In fractures the over-riding of the broken ends of a bone is often due to the contractions of the muscles that are the result of their tonicity. The tone of skeletal muscles is due to stimuli from the central nervous system.

Visceral and cardiac muscle exhibit tone even when isolated from the nervous system. The maintenance of normal blood-pressure is partly dependent upon the tone of the muscles in the walls of the arteries. Likewise healthy digestion is dependent upon the tone of the muscles of the stomach and intestines. The tone of visceral and cardiac muscles is inherent in them and is also partly due to substances in the blood, *i.e.*, sodium, potassium, and calcium salts, and secretions from the ductless glands as well as to stimuli from the nervous system.

Classification

Like every other tissue, muscular tissue is composed of cells and intercellular substance, with this difference, that the cells become

elongated and are usually termed fibers. The intercellular substance consists of a small amount of cement, which helps to hold the cells together, or to the framework of connective tissue in which they are embedded.

Muscular tissue may be classified according to its structure or location:

Structure	Location
Striated or cross-striped	Skeletal
Non-striated or smooth	Visceral
Indistinctly striated	Cardiac

FIG. 72. — SKELETAL MUSCLE CELLS. (Magnified thirty times.) Courtesy of Mayo Clinic.

Striated or cross-striped muscular tissue. — This tissue is called striated because of the horizontal striæ or parallel cross-stripes which characterize its microscopic appearance. It is also called skeletal because it forms the muscles which are attached to the skeleton, somatic because it forms the body-wall, and voluntary because the movements accomplished by it are voluntary. It is composed of spindle-shaped fibers which may be 38 mm. ($1\frac{1}{2}$ in.) long and from 0.01 to 0.1 mm. ($\frac{1}{2500}$ to $\frac{1}{250}$ in.) in diameter. These fibers, which are modified cells, consist of a tubular sheath, called *sarcolemma,* which encloses a soft contractile substance. On the internal surface of the sarcolemma elongated nuclei are seen. Micro-dissection shows white fibrils (fibrillæ) which are closely

packed together and run lengthwise through the entire fiber. A small amount of fluid material, called sarcoplasm, surrounds the fibrillæ.

The muscle cells lie closely packed, their ends lapping over onto adjacent cells, forming bundles. Connective tissue forms a supporting framework for muscular tissue. It penetrates between the cells and surrounds the small bundles, grouping them into larger bundles. It also surrounds the larger bundles and forms a covering for the whole muscle. This connective tissue carries an intricate network of blood-vessels and nerves. Every muscle cell comes into close contact with capillaries, and is surrounded with lymph. Every muscle cell is the seat of nerve endings.

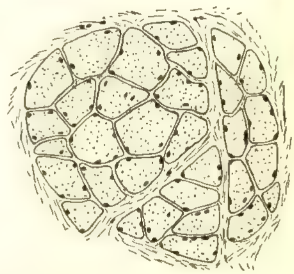


FIG. 73.—TRANSVERSE SECTION OF MUSCLE BUNDLE. Bundles (fasiculi) of muscle fibers with nuclei near surface of the fibers. Connective tissue surrounds each fiber. Wider areas of connective tissue surround bundles of fibers.

Skeletal muscles. — The skeletal muscles are separate organs, each one having its own sheath of connective tissue, called epimysium. They vary in length from a fraction of a centimeter to nearly 60 cm. (24 in.) and are very diverse in form. In the trunk the muscles are broad, flattened, and expanded, forming the walls of the cavities which they enclose. In the limbs they are of considerable length, forming more or less elongated spindles or straps. A typical muscle is described as consisting of a body and two extremities. The body is the red contracting part, and the extremities are the ends where they are attached.

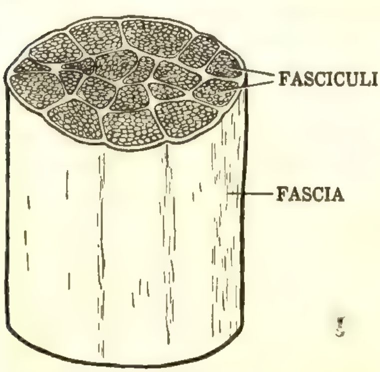


FIG. 74. — A SECTION OF VOLUNTARY MUSCLE TRUNK COMPOSED OF FASICULI COVERED WITH FASCIA.

Origin and insertion. — It is customary to speak of the attachments of the opposite ends of muscles under the names of origin and insertion, the first term *origin* being usually applied to the more fixed attachment; the second term *insertion* being applied to the more movable attachment. The origin is absolutely fixed in only a very small number of muscles, such as those

of the face, which are attached by one end to bone and by the other to skin.

Each muscle contracts lengthwise and thus pulls the attachments at either end nearer to each other. It increases in diameter as it contracts lengthwise so that it does not become smaller but merely changes its shape.

Tendons and aponeuroses. — Some muscles have their origin in the periosteum of bone, others have an intervening tendon between the periosteum and the muscle. The insertion of muscles is either by tendons or aponeuroses. As the end of a muscle is approached, the connective tissue which forms a framework for the muscle fibers and an outside sheath for the whole muscle increases in quantity and usually extends beyond the muscle fibers. This extension is dense and white and forms round or flattened cords called tendons, or expanded sheets called aponeuroses.

Fasciæ. — As previously stated (page 45), most of the muscles are closely covered by sheets of fibrous tissue called fasciæ. These fasciæ not only envelop and bind down the muscles, but also separate them into groups. Such groups are named according to the parts of the body where they are found, *viz.:* cervical fascia, thoracic fascia, abdominal fascia, pelvic fascia, etc. Individual fasciæ are frequently given the names of the muscles which they envelop and bind down, *viz.:* temporal fascia, pectoral fascia, deltoid fascia, etc. In the vicinity of the wrist and ankle, parts of the deep fascia become blended into tight transverse bands, which serve to hold the tendons close to the bones. These bands are called *annular ligaments*.

It is important to realize the continuity of the connective tissues of the body. Tendons, ligaments, and fasciæ blend with periosteum; tendons and fasciæ serve as ligaments; tendons lose themselves in fasciæ; and tendons of some muscles serve as fasciæ for others.

Function. — The function of skeletal muscles is to operate the bones of the body, thereby producing motion.

Non-striated or smooth muscular tissue. — This tissue is called smooth muscle because it does not exhibit cross stripes or striæ. It is called *visceral* because it constitutes a large portion of the walls of the viscera. The motions caused by smooth muscle are involuntary. Usually we have no consciousness of them. Smooth muscle tissue is composed of spindle-shaped cells containing a single large nucleus embedded in the cell substance. These cells are always much shorter than the cells of striated muscle tissue and are

held in place by a network of connective tissue which carries blood-vessels and nerves. In most parts of the body smooth muscle tissue is arranged as a tube which forms the walls of the part concerned, *e.g.*, the intestines and blood-vessels. It usually consists of two main layers, one called the *circular*, the other the *longitudinal* layer or coat. The circular coat is the thicker.

Function. — The function of smooth muscle is to cause visceral motion.

Cardiac muscular tissue. — This variety of muscular tissue is found in the heart substance. It is composed of cells which are not as distinctly striated as the cells of skeletal muscle. The cells are quadrangular in shape, are joined end to end, and grouped in bundles with connective tissue forming a supporting framework.

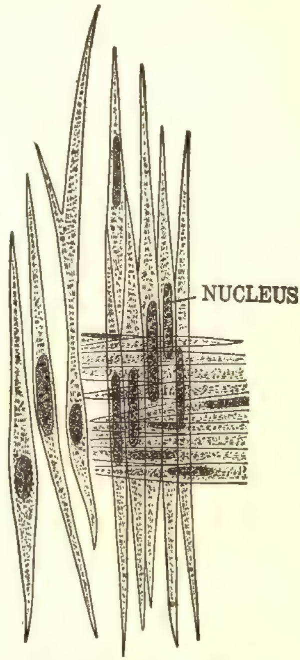


FIG. 75. — PLAIN MUSCLE CELLS FROM INTESTINE. At the left, isolated cells; at the right, cells from the longitudinal and circular layers crossing.

Stimuli. — All protoplasm possesses the property of *excitability*. Any force which affects this excitability, *i.e.*, increases or decreases it, is called a stimulus. Protoplasm also possesses the property of *conductivity*, and when stimulated at one point, the response may be effected in a remote part. The response is the characteristic one for the tissue stimulated. In the muscles the characteristic response is contraction. Normally the muscles are stimulated by impulses conveyed by nerves. Various other forms of stimuli are used in laboratory work and are called artificial stimuli.

Nerves. — Muscular tissue is well supplied with nerves. Certain fibers have sensory end organs in the muscles. These convey to the central nervous system the state of contraction of the muscle and are called sensory fibers. Certain other fibers convey impulses from the central nervous system to the muscles and control their contraction. These are called motor fibers. If a motor nerve is severed or the center in the brain or cord is damaged, the muscle is said to be paralyzed. In other words no stimulus is carried to the muscle and there is no response, even though the muscle itself is intact. If a sensory nerve is severed, sensation is

lost because stimuli are not carried from the end-organ of the severed nerve to the central nervous system.

Varieties of muscular movements. — We classify movement as voluntary or under conscious control and involuntary or removed from conscious control. Voluntary movements are produced by the skeletal muscles. These muscles also produce a few involuntary movements such as coughing and sneezing. Cardiac and visceral muscles produce involuntary movements which go on in the interior of our bodies. We do not control these movements and usually are not even conscious of them. Nevertheless involuntary muscle tissue is under the control of the nervous system. The voluntary movements of the skeletal muscles are due to stimuli

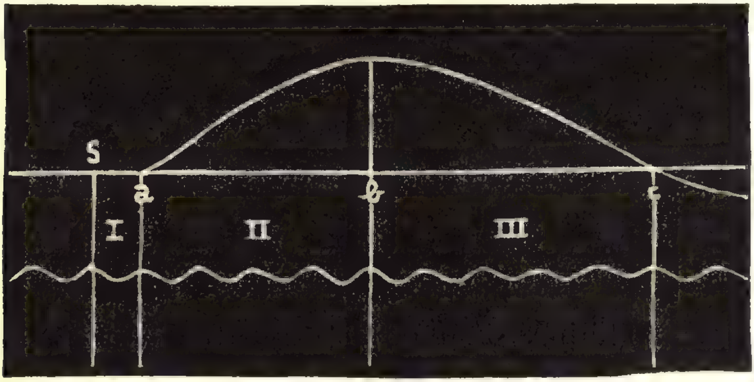


FIG. 76. — CURVE OF A SIMPLE CONTRACTION OF A MUSCLE. *S* indicates the time when the stimulus enters the muscle. Phase I (*S* to *a*) is the *latent period* and in isolated frog muscle lasts about 0.01 sec. Phase II (*a* to *b*) is the *phase of shortening* and lasts about 0.04 sec. Phase III (*b* to *c*) is the *phase of relaxation* and lasts about 0.05 sec. From crest to crest of the wavy line below represents an interval of 0.01 second. The apparatus for recording a muscle contraction is shown in next figure.

from the central nervous system.[1] Every step that we take is the result of distinct acts on the part of nerve centers in the brain. The contractions of visceral muscle are under the control of the autonomic system. We must become familiar with the idea that stimuli from the nervous system not only excite muscular activity

[1] M. R. Lewis reports in publication 272 of the Carnegie Institution of Washington: Skeletal muscle fibers growing from the breast of a ten or eleven day chick embryo explanted into nutrient Locke's solution were observed to contract spontaneously sometimes for fifteen or twenty minutes. The contraction of the skeletal muscle did not resemble that *in vivo* but was more like muscle twitching. It took place in only a few of the fibers in a culture and only in cultures having an abundant growth of the fibers. It could be started occasionally by bathing the growth with fresh medium. The heart muscle and smooth muscle contracted in cultures as *in vivo*.

(as in the skeletal muscles) but also increase or decrease the degree of activity. The influence of the nervous system on the activity of visceral muscular tissue is the latter, *i.e.*, to increase or decrease it.

Conditions of contraction. — Skeletal muscle is essentially a quick-acting tissue. It contracts quickly and relaxes promptly. In sharp contrast to this, the contractions of visceral muscle develop slowly, are maintained for some time, and fade out slowly. The contraction of any skeletal muscle is the result of a series of stimuli discharged rhythmically by the nerve fibers innervating it. If one of these contractions is analyzed, it will be found that there is a brief period after the muscle is stimulated before it contracts. This is called the latent period and is followed by a period of contraction, which in turn is followed by a period of relaxation. If we give 0.10 of a second as the reaction time, 0.01 might represent the latent period, 0.04 the contraction period, and 0.05 the relaxation period.[2] It has been demonstrated experimentally, by applying electrical stimuli to a muscle, as for instance the gastrocnemius muscle, and recording the contractions on a moving drum, that the contractions vary depending upon (1) the strength of the stimulus, in general the stronger the stimulus up to a certain maximum the higher the contraction will be; (2) the duration of the stimulus,

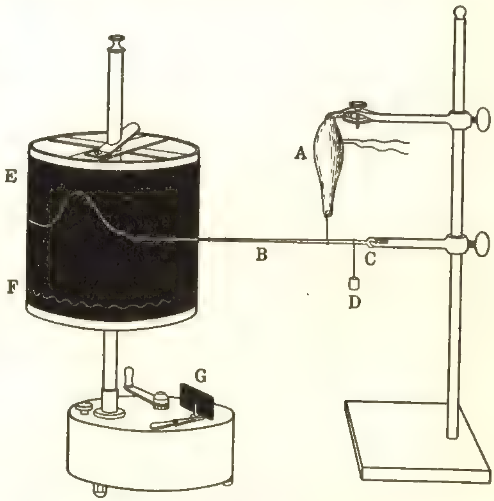


FIG. 77. — RECORD MADE BY A CONTRACTING MUSCLE. *A*, muscle extending from clamp to writing lever; *B*, writing lever, hinged at *C* and counterweighted at *D*; *E*, revolving smoked drum, on which the point of the writing lever draws a line; *F*, time record — from crest to crest of a wave may be 0.01 sec. *G*, fan for regulating speed. A muscle is attached to the lever which is arranged to draw a line on the moving surface. This line will record the movement of the lever. When the muscle contracts the lever will be raised and then when the muscle relaxes the lever will fall. Thus a curve of muscle contraction may be recorded.

[2] These figures have been obtained experimentally and differ for different muscles and for the muscles of different animals.

the highest contractions result from stimuli of moderate duration. (3) The weight of the load influences the height of the contractions. Some load is necessary in order to get the best response; increase of load decreases the height of contractions. (4) Muscles do their best work at a certain optimum temperature. For man this is about 37° C. (98.6° F.) body temperature. If the temperature is raised much above this, the muscle loses its excitability and becomes functionally depressed, entering finally the state of heat rigor, *i.e.*, a condition of permanent shortening.

The metabolic changes taking place in muscle during contraction and recovery are not certainly known. Some glycogen is changed to lactic acid, however, oxygen is required for the recovery process, some of the lactic acid is oxidized to carbon dioxide and some rebuilt into glycogen. It is thought that the cleavage of phosphocreatine into creatine and phosphoric acid yields the initial energy for contraction, and that other protein-phosphates enter into the changes yielding the energy for the reconstitution of the phosphocreatine, themselves being reconstituted eventually by the oxidation of lactic acid.

Tetanus. — If a second stimulus is applied to a muscle before relaxation from the first stimulus is complete, the second contraction will take place before the first recovery is completed and if the stimuli are applied rapidly, 20–25 or more per second, there will be no apparent relaxation between the contractions. This sustained contraction is spoken of as tetanic. Probably all of our muscular contractions are the result of series of stimuli reaching the muscles over the nerves with such rapidity as to prevent apparent relaxation, yielding the sustained contractions with which muscular work is accomplished. It is especially to be noted in the muscular contractions which hold the body erect and enable us to carry loads.

Blood-supply and source of energy. — All varieties of muscular tissue are well supplied with blood-vessels which are supported and carried by the connective tissue. They do not penetrate into the cells, but each cell is bathed in lymph which exudes from the blood-vessels. One of the substances brought by the blood to the muscles is glucose, which is stored in the cells as glycogen. This represents chemical energy, which stimuli may transform into mechanical energy. Muscles may be compared to engines capable of converting chemical energy into mechanical energy. During the various phases of contraction of a muscle, glycogen is used up, lactic acid and carbon dioxide are formed, and heat is liberated. The amount of lactic acid produced is directly related to the amount

of glycogen used. At first the carbon dioxide and lactic acid increase the irritability, but this increased irritability is soon lost and excessive amounts have an opposite effect. These waste substances must be eliminated, and except in cases of prolonged contractions, the system is able to get rid of them readily.

Fatigue. — Prolonged contractions result in *fatigue,* and this means two things: (1) an accumulation of waste substances which act as poisons, (2) a loss of nutritive material. A period of rest furnishes opportunity for the blood to carry the fatigue substances to the excretory organs and nutritive material to the muscles. In cases of extreme fatigue resulting from prolonged overwork the fatigue substances circulate in the blood and lessen the irritability of muscular tissue so that it fails to respond to stimuli. It has been demonstrated that the injection of the blood of a fatigued animal into a rested one will promptly bring on signs of fatigue. It must not be thought that the state which we ordinarily recognize in ourselves as fatigue is entirely muscular. The sense of fatigue is very complex and is often associated with such mental states as lack of interest, lack of will power, laziness, etc.

SKELETAL MUSCLES

The names of the skeletal muscles are of Latin derivation, hence they have two names, one Latin and the other English, *e.g.,* obliquus externus abdominis and external abdominal oblique. Sometimes a muscle may have more than one Latin name, *e.g.,* psoas magnus and psoas major, vastus intermedius and vastus crureus. Frequently a muscle has no well-known English name, *e.g.,* levatores costarum; sometimes the English name is the one that is best known, *e.g.,* deltoid instead of deltoideus. More and more anatomists are coming to use the Basle Anatomical nomenclature (B. N. A.[3]) although in some cases the Latin name has not come into general use. In this section an endeavor has been made to give the Latin and the English names.

Almost all the skeletal muscles occur in pairs. A few single muscles situated in the median line represent the fusion of two muscles. Skeletal muscles are usually arranged in antagonistic groups, one of which opposes the other. Thus the muscles located

[3] The expression B. N. A. is the title of a list of some 4500 anatomical terms (nomina anatomica) accepted at Basle in 1895 by the Anatomical Society as the most suitable designations for the various parts of the human anatomy. The terms are all in correct Latin and have been selected by a group of the most distinguished anatomists in the world. Quoted from Anatomical Terminology by Lewellys F. Barker.

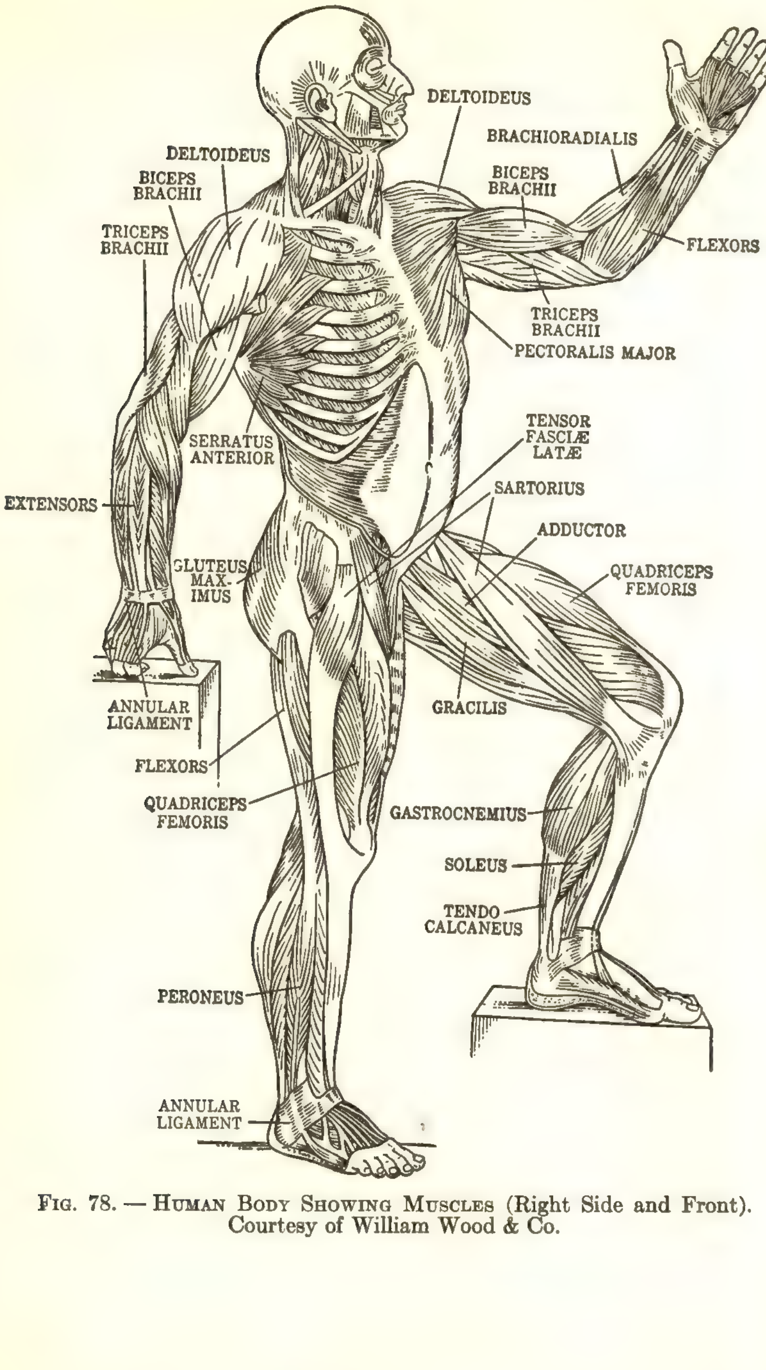


FIG. 78. — HUMAN BODY SHOWING MUSCLES (Right Side and Front). Courtesy of William Wood & Co.

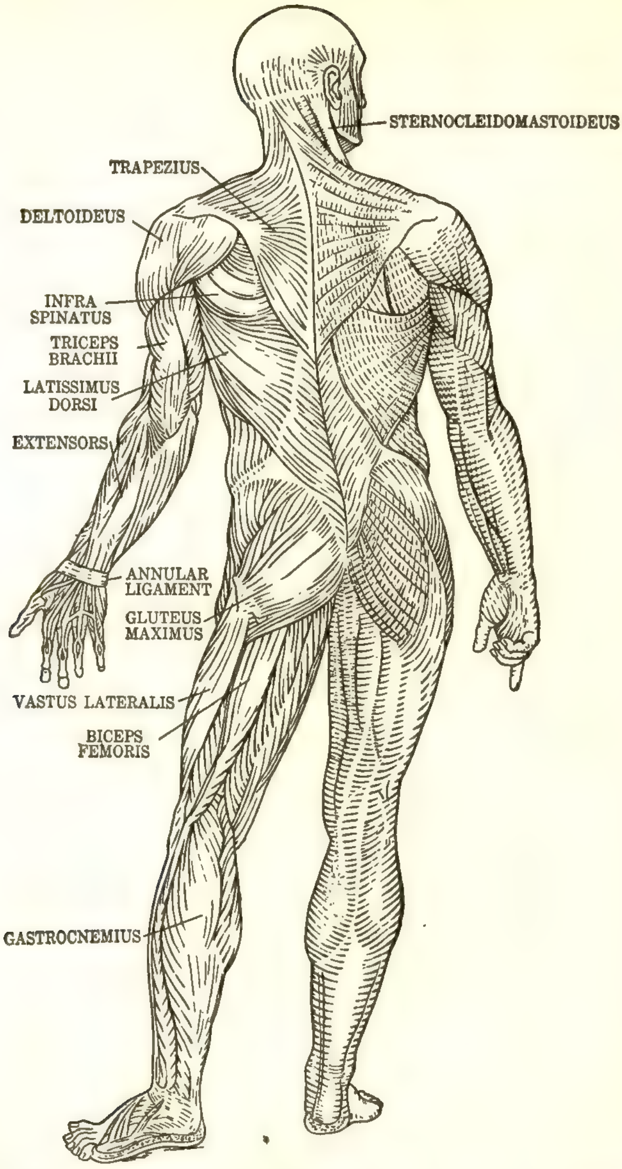


FIG. 79. — HUMAN BODY SHOWING MUSCLES. (Back.) Courtesy of William Wood & Co.

on the anterior surface of the arm and forearm are called flexors, and those located on the posterior surface are called extensors. The action of the flexors is to bend the arm, the action of the extensors is to extend or straighten the arm. When either the flexors or the extensors contract, the opposing group undergoes a degree of relaxation but it is not wholly devoid of tone.

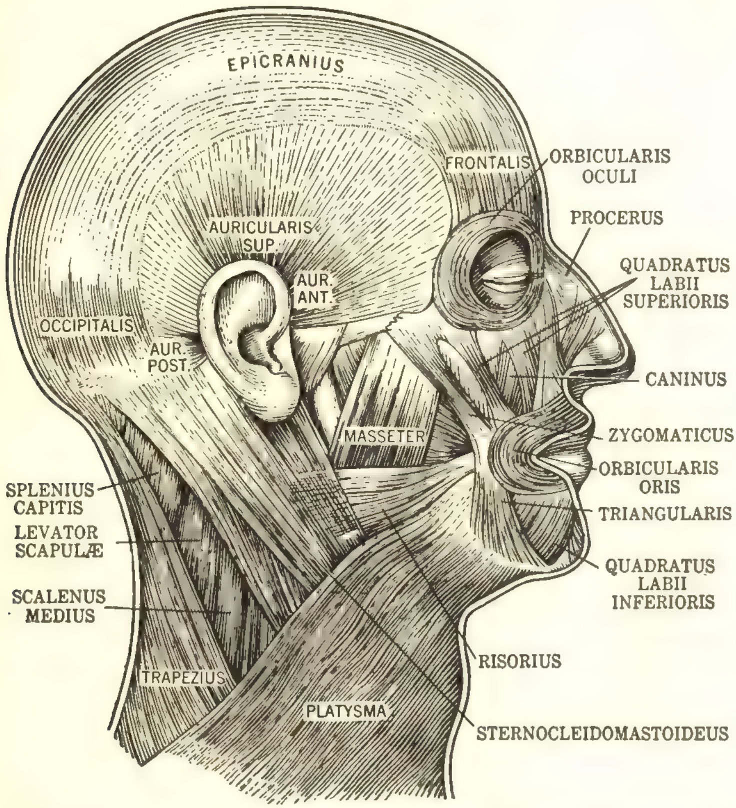


FIG. 80. — SUPERFICIAL MUSCLES OF HEAD AND NECK. (Gerrish.)

CHIEF MUSCLES OF HEAD, FACE, TONGUE, AND NECK

Muscles of the head. — The chief muscle of the head is the epicranial, or occipito-frontalis, which may be considered as two muscles, the occipital which covers the back or occiput of the head, and the frontal which covers the front of the skull. The two muscles are held together by a thin aponeurosis extending over and covering the whole of the upper part of the cranium.

The occipital takes its origin[4] from the occipital bone and the mastoid portion of the temporal bone and is inserted into the aponeurosis. The frontal takes its origin from the aponeurosis, and is inserted into the tissues in the region of the eyebrows.

Action. — The frontal portion of this muscle is the more powerful; by its contraction the eyebrows are elevated, and the skin of the forehead thrown into transverse wrinkles. The occipital portion draws the scalp backward.

Muscles of the face. — There are about thirty facial muscles. Only a few are considered. We group them as:

Muscles of the Face	Muscles of the orbit and eyelids	Four recti. Two oblique. Levator palpebræ superioris. Orbicularis oculi.
	Muscles of mastication	Masseter. Temporal. Internal pterygoid. External pterygoid.
	Muscles of the lips	Orbicularis oris. Buccinator.

Muscles of the orbit and eyelids. — The orbit contains seven muscles; six of them are attached to the eyeball, and are arranged in three opposing pairs.

The four recti muscles, called respectively superior, inferior, medial, and lateral, arise at the apex of the orbital cavity. Each muscle passes forward in the position which its name indicates and is inserted into the eyeball.

The two oblique muscles are called respectively superior and inferior. The superior oblique arises from the apex of the orbit, courses forward to the upper and inner angle of the orbit, where it passes through a ring of cartilage, then it bends at an acute angle, passes around the upper part of the eyeball and is inserted between the superior and lateral recti. The inferior oblique arises from the orbital plate of the maxilla and passes around the under portion of the eyeball to its attachment between the inferior and lateral recti.

Action. — The four recti acting singly turn the corneal surface of the eye upward, downward, inward, or outward, as their names suggest. The action of the two oblique muscles is somewhat complicated, but their general tendency is to roll the eyeball on

[4] The origin and insertion of some muscles are very complex. The origin may be a limited area of one bone, or parts of more than one. The same is true of the insertion. It is impossible to give this detail in limited space. The origin and insertion may show on the illustrations or can be found in detailed textbooks of anatomy.

its axis. These muscles do not act singly but rather coöperatively and with a high degree of coördination.

The levator palpebræ superioris (lifter of the upper lid) arises from the apex of the orbit, passes forward, and is inserted into the tarsal cartilage of the upper lid.

Action. — It raises the upper lid and opens the eye.

Orbicularis oculi (circular muscle of the eye) arises from the nasal portion of the frontal bone, from the frontal process of the maxilla, and from a short fibrous band, the medial palpebral (tarsal) ligament. It spreads lateralward, forming a broad, thin

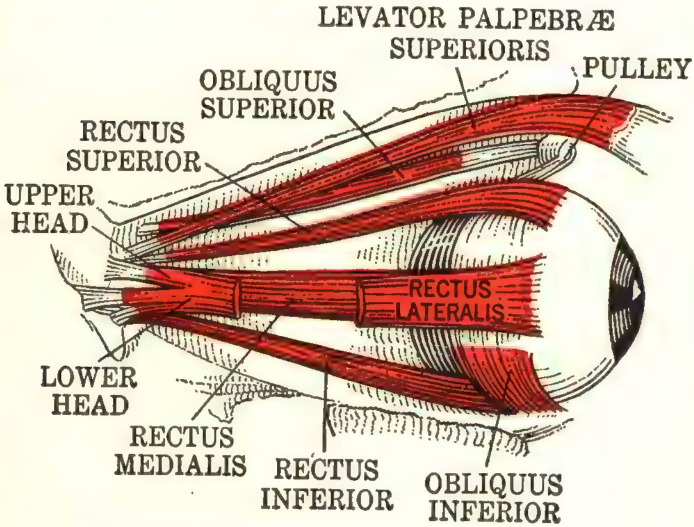


FIG. 81. — MUSCLES OF THE RIGHT ORBIT.

layer which occupies the eyelid, and is inserted at the union of the upper and lower lid at the outer side of the eye. This is called the palpebral portion. A broader, thicker part, called the orbital portion, surrounds the circumference of the orbit, spreads over the temple, and downward on the cheek; its fibers form a complete ellipse, the upper ones being inserted in the frontalis muscle.

Action. — It serves as a sphincter muscle of the eyelids. The action of the palpebral portion is involuntary. It closes the lids gently as in sleep or blinking. The orbital portion is under the control of the will. The action of the entire muscle is to close the lids forcibly, drawing the parts toward the inner angle and tightening the brow.

Muscles of mastication. — They are: (1) the masseter (chewing muscle), (2) the temporal (temple muscle), (3) the internal pterygoid, and (4) the external pterygoid.

The masseter arises from the zygomatic process and adjacent portions of the maxilla and is inserted into the angle and lateral surface of the ramus of the mandible.

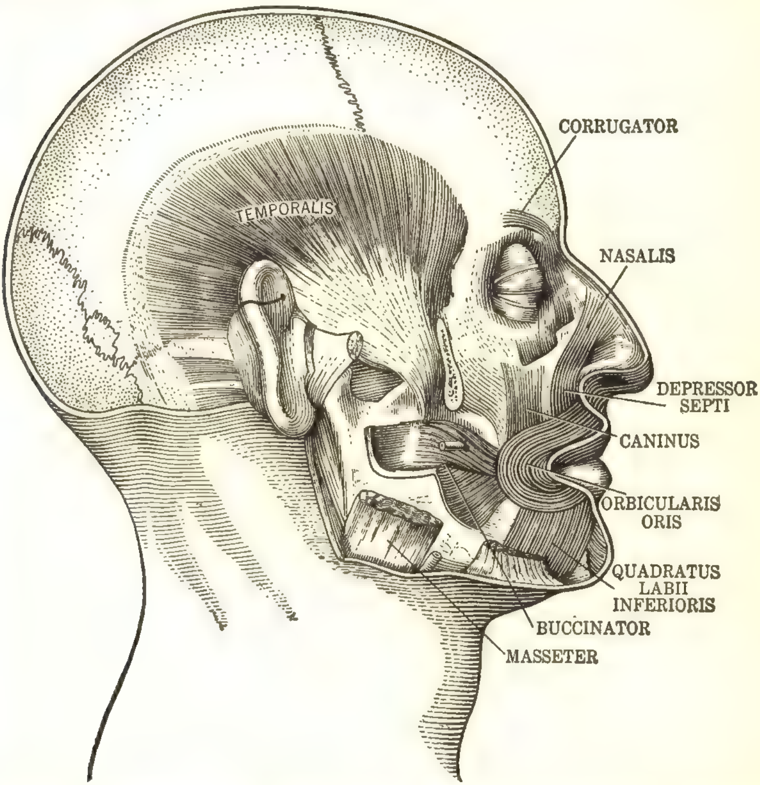


FIG. 82. — TEMPORAL AND DEEP MUSCLES ABOUT THE MOUTH. (Gerrish.)

The temporal (temporalis) arises from the temporal fossa of the skull and the deep surface of the temporal fascia by which it is covered. It is inserted into the coronoid process of the mandible.

The internal pterygoid (pterygoideus internus) arises from the medial surface of the lateral pterygoid plate, the pyramidal process of the palatine bone, and the tuberosity of the maxilla. The fibers pass downward, lateralward, and backward, to be inserted into the ramus of the mandible.

The external pterygoid (pterygoidus externus) is a short, thick muscle which arises by two heads, an upper from the zygomatic

surface of the great wing of the sphenoid and a lower from the lateral surface of the pterygoid plate. The fibers extend backward and are inserted in front of the neck of the condyle of the mandible and into the articular disc of the joint between the temporal and the mandible bones.

Action. — The masseter, temporal, and internal pterygoid raise the mandible against the maxillæ. The posterior fibers of the temporal retract the mandible. The external pterygoid assists in opening the mouth, and the internal and external pterygoids

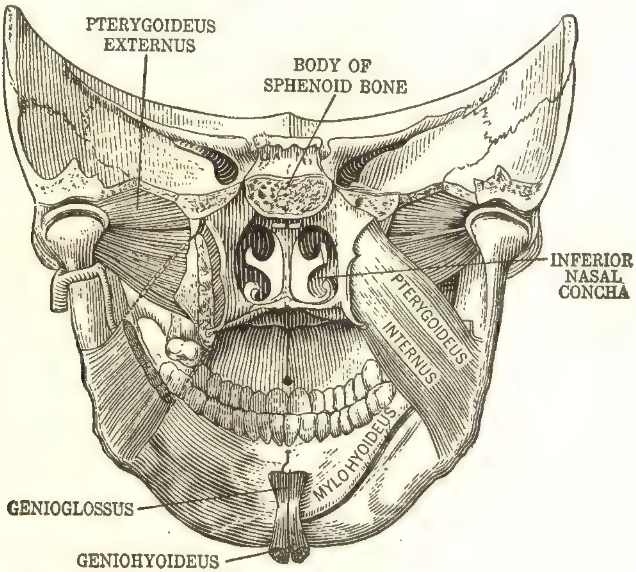


FIG. 83. — PTERYGOID MUSCLES. Viewed from behind, the back portion of the skull having been removed. (Gerrish.)

acting together cause the lower jaw to protrude, so that the lower teeth are projected in front of the upper. The internal and external pterygoids of one side produce lateral movements of the jaw such as take place during the grinding of food.

Muscles of the lips. — We shall consider only two important muscles related to the orifice of the mouth.

The orbicularis oris (ring-shaped muscle of the mouth) consists of numerous layers of muscular fibers which surround the opening of the mouth and pass in different directions. Some of the fibers are derived from other facial muscles which are inserted into the lips; some fibers proper to the lips pass in an oblique direction from the under surface of the skin through the thickness of the

lips to the mucous membrane; other fibers connect the maxillæ and septum of the nose above with the mandible below.

Action. — It causes compression and closure of the lips in various ways, *e.g.*, tightening the lips over the teeth, contracting them, or causing pouting or protrusion of one or the other.

The buccinator (trumpeter's muscle) arises from the alveolar processes of the maxilla and mandible. The fibers converge toward the angle of the mouth, and are inserted into the orbicularis oris.

Action. — It compresses the cheek so that during mastication the food is kept under pressure of the teeth.

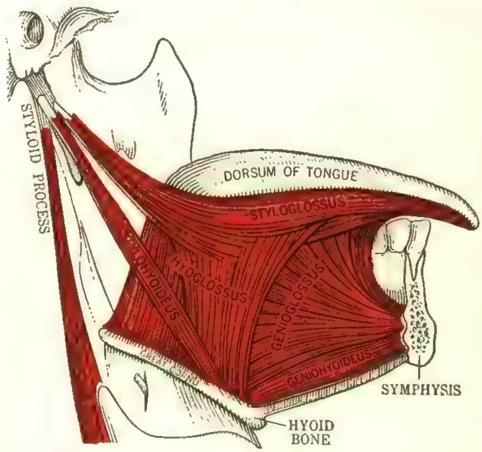


FIG. 84. — SOME OF THE MUSCLES OF THE TONGUE. Viewed from the right side.

Muscles of the tongue. — The tongue is made up of muscular tissue and is divided into two halves by a fibrous septum which is attached below to the hyoid bone. In each half there are two sets of muscles; the *extrinsic* have their origin outside the tongue, and the *intrinsic* are contained within it. Two of the extrinsic muscles are the genioglossus and the styloglossus.

The genioglossus arises by a short tendon from the inner surface of the mandible at the symphysis and spreads out in a fan-like form. It is attached by a thin aponeurosis to the hyoid bone, and the fibers are inserted the whole length of the under surface of the tongue, in and at the side of the midline.

Action. — It thrusts the tongue forward, retracts it, and also depresses it.

The styloglossus has its origin in the styloid process of the temporal bone, and is inserted in the whole length of the side and under part of the tongue.

Action. — It draws the tongue upward and backward.

During general anesthesia these, together with all the other muscles, become relaxed, and it is necessary to press the angle of the lower jaw upward and forward in order to prevent the tongue from falling backward and obstructing the larynx.

trace [illegible] with muscle

Muscles of the Neck { Platysma. Sternocleidomastoideus.

The platysma (broad sheet muscle) arises from the skin and fasciæ, covering the pectoral and deltoid muscles, and is inserted in the mandible and muscles about the angle of the mouth.

Action. — It depresses the mandible and draws down the lower lip and angle of the mouth.

The sternocleidomastoid (sternocleidomastoideus) muscle is named from its origin and insertion. It arises by two heads from the upper part of the sternum and the inner border of the clavicle and is inserted by a strong tendon into the mastoid portion of the temporal bone. This muscle is easily recognized in thin persons by its forming a cord-like prominence obliquely situated along each side of the neck.

Action. — When one muscle acts alone, it draws the head toward the shoulder of the same side. Both muscles acting together flex the head in a forward direction and in forced inspirations they assist in elevating the thorax. If one of these muscles be either abnormally contracted or paralyzed, we get the deformity called *torticollis* or wry neck.

CHIEF MUSCLES OF THE TRUNK

Muscles of the Back {
- Trapezius.
- Latissimus dorsi.
- Sacrospinalis (Erector spinæ) { Iliocostalis. Longissimus. Spinalis.

The muscles of the back are disposed in five layers. Our list includes only two large muscles, the trapezius and latissimus dorsi, which form the superficial layer, and the sacrospinalis which forms one of the deep layers.

The trapezius, so called because right and left together make a large diamond-shaped sheet, arises from the occipital bone, the ligamentum nuchæ, the spinous processes of the seventh cervical and the twelve thoracic vertebræ. ~~From this extended line of origin~~ The fibers converge to their insertion in the clavicle, ~~the acromion process,~~ and ~~the spine of~~ the scapula. It is a very large muscle, and covers the other muscles of the upper part of the back and neck, ~~also the upper portion of the latissimus~~ dorsi.

Action. — If the upper end is fixed, the shoulder is raised, as in shrugging the shoulder or carrying weights on the shoulder. If the shoulders are fixed, contractions of both muscles will draw the head backward; if only one muscle contracts, the head is drawn to

that side. Contraction of the whole muscle ~~retracts~~ the scapula and braces back the shoulder.

The latissimus dorsi arises from the lower six thoracic vertebræ, and through the medium of the lumbodorsal fascia,[5] from the spines of the lumbar and sacral vertebræ, from the posterior third

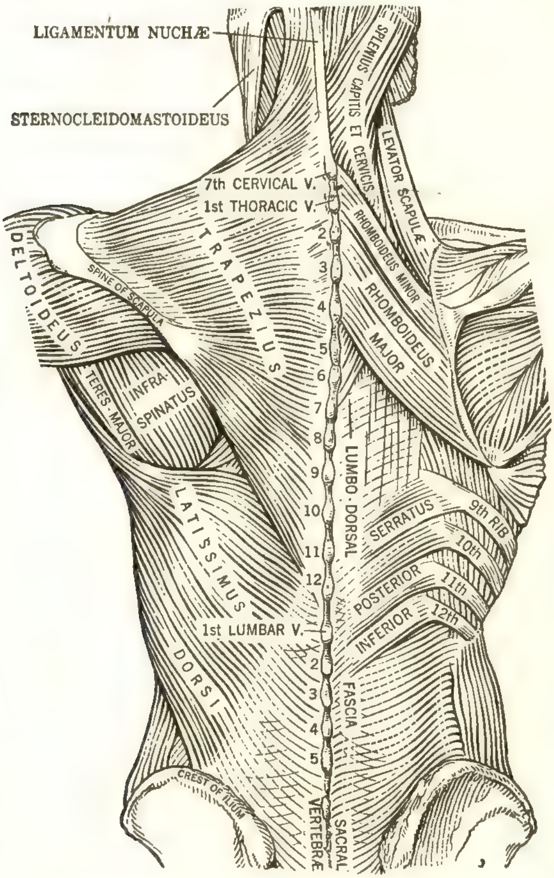


FIG. 85. — DIAGRAM SHOWING SOME OF THE MUSCLES OF THE SHOULDERS AND BACK.

of the crest of the ilium, and from the lower three or four ribs. From this extensive origin the fibers pass in different directions so as to converge into a four-sided tendon which is inserted into the lower part of the intertubercular groove of the humerus.

[5] The lumbodorsal fascia or lumbar aponeurosis is a deep investing membrane which covers the deep muscles of the back of the trunk.

Action. — It depresses the humerus and draws it backward, also rotates it inward.

The sacrospinalis (erector spinæ) arises from the lower and posterior part of the sacrum, the posterior portion of the iliac crests, the spines of the lumbar and the lower two thoracic vertebræ. The fibers form a large mass of muscular tissue which splits in the upper lumbar region into three columns, namely, a lateral, the *iliocostalis,* an intermediate, the *longissimus,* and a medial, the *spinalis.* Each of these consists from below upward of three parts.

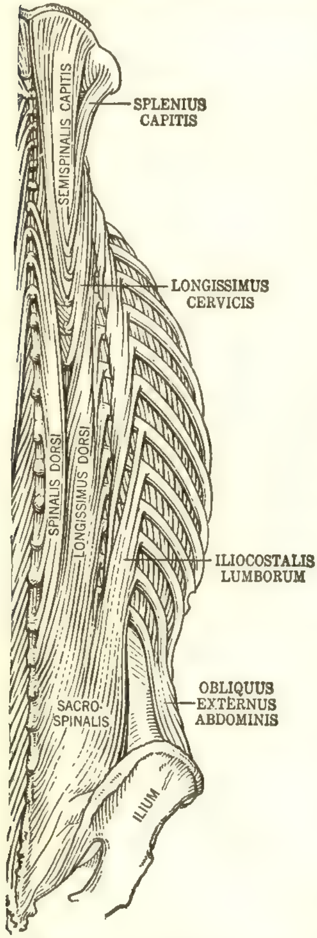


FIG. 86. — DIAGRAM TO SHOW SOME OF THE MUSCLES OF THE BACK.

These muscles are attached to the ribs and vertebræ at different levels all the way up the back to the occipital bone and the mastoid process of the temporal bone. As the muscle climbs up the back it does not relinquish one foothold before it establishes another. The result is not merely a continuity of structure but overlapping, as one segment begins back of the insertion of the segment below it.

Action. — This muscle serves to maintain the vertebral column in the erect posture.[6]

Muscles of the Chest $\left\{\begin{array}{l}\text{Pectoralis major.}\\ \text{Pectoralis minor.}\\ \text{Serratus anterior}\\ \quad\text{(serratus magnus).}\end{array}\right.$

The pectoralis major arises from the anterior surface of the sternal half of the clavicle, the anterior surface of the sternum, the cartilages of the true ribs, and the aponeurosis of the external oblique. The fibers converge and form a thick mass, which is inserted by a flat tendon into the crest of the greater tubercle of the humerus.

[6] When there is abdominal distension as in pregnancy or ascites this muscle bends the trunk backward in order to counterbalance the weight. The bending of the vertebral column backward is responsible for the peculiar gait of advanced pregnancy.

Action. — If the arm has been raised, the pectoralis major acting with other muscles[7] draws the arm down to the side of the chest. Acting alone it adducts and draws the arm across the chest, also rotates it inward.

The pectoralis minor is underneath and entirely covered by the pectoralis major. It arises from the upper margins and outer

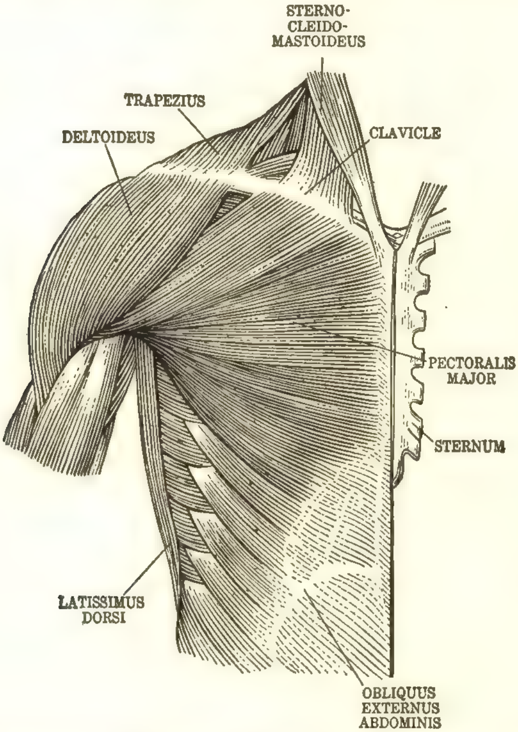


FIG. 87. — SUPERFICIAL MUSCLES OF FRONT OF CHEST AND SHOULDER OF RIGHT SIDE. (Gerrish.)

surfaces of the third, fourth, and fifth ribs near their cartilages, and is inserted into the coracoid[8] process of the scapula.

Action. — It depresses the point of the shoulder and rotates the scapula downward. In forced inspiration the pectoral muscles help in drawing the ribs upward and expanding the chest.

The serratus anterior (serratus magnus) arises from the outer surfaces and superior borders of the upper eight or nine ribs and from the intercostals between them. The fibers pass upward and

[7] The latissimus dorsi and the teres major. For the latter see Fig. 88.
[8] See Fig. 56 for coracoid process of scapula.

backward and are inserted in various portions of the ventral surface of the scapula.

Action. — It carries the scapula forward and raises the vertebral border of the bone as in pushing. It assists the trapezius in raising

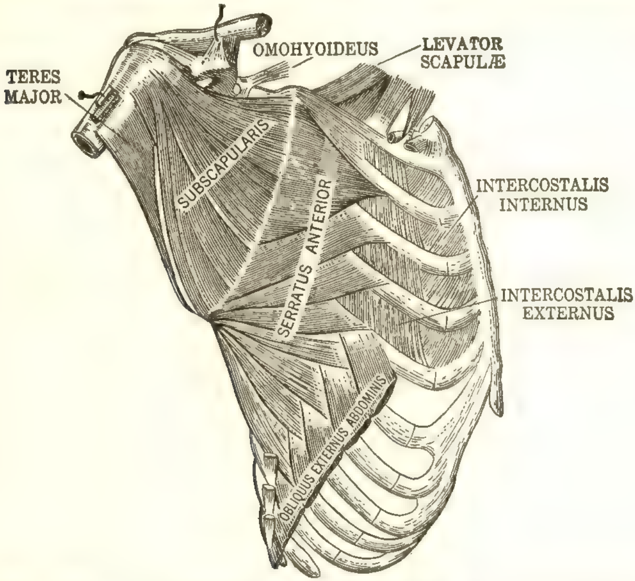


FIG. 88. — SERRATUS ANTERIOR OF RIGHT SIDE. The scapula has been turned backward and drawn outward.

the acromion process and supporting weights on the shoulder. It also assists the deltoid in raising the arm.

Muscles of the Thorax { External intercostals. Internal intercostals. Levatores costarum.

The intercostal muscles (intercostales) are found filling the spaces between the ribs. Each muscle consists of two layers, one external and one internal, and as there are eleven intercostal spaces on each side, and two muscles in each space, it follows there are forty-four intercostal muscles. The fibers of these muscles run in opposite directions.

The external intercostals (intercostales externi) extend from the tubercles of the ribs behind to the cartilages of the ribs in front, where they end in membranes which connect with the sternum. Each arises from the lower border of a rib and is inserted into the upper border of the rib below. The direction of the fibers is obliquely downward.

The internal intercostals (intercostales interni) extend from the sternum to the angle of the ribs and are connected with the vertebral column by thin aponeuroses. Each arises from the inner surface of a rib and is inserted into the upper border of the rib below. The direction of the fibers is obliquely downward and opposite to the direction of the external intercostals.

Action. — Investigators disagree as to the functions of the intercostal muscles. One authority states that the external and internal intercostals contract simultaneously and prevent the intercostal spaces from being pushed outward or drawn inward during respiration. Another classes them as inspiratory.

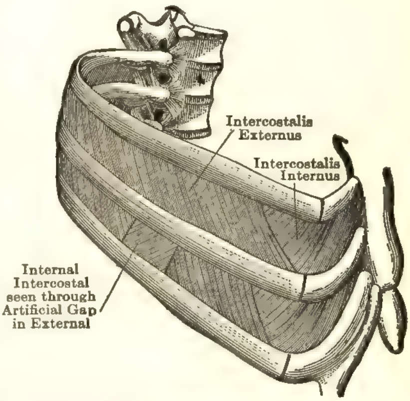


FIG. 89. — INTERCOSTAL MUSCLES IN RIGHT WALL OF THORAX. (Gerrish.)

The levatores costarum are twelve small muscles which arise from the transverse processes of the vertebræ from the seventh cervical to the eleventh thoracic. They pass obliquely downward and lateralward like the external intercostals. Each one is inserted into the outer surface of the rib, just below the vertebra from which it takes origin.

Action. — Some authorities state the levatores costarum have little action on the ribs, but act as rotators and lateral flexors of the vertebral column. Other authorities class them as inspiratory muscles.

The diaphragm is a dome-shaped, musculo-fibrous partition which forms the convex floor of the thoracic cavity and the concave roof of the abdominal cavity. The peripheral muscular fibers arise from the lower circumference of the thorax and are inserted into a central tendon. The fibers are grouped according to their origin into three parts: the *sternal*, which arise from the back of the xiphoid process; the *costal*, which arise from the cartilages of the lower six ribs on either side; the *lumbar*, which arise from the *lumbocostal arches* [9] and the lumbar vertebra by two pillars or

[9] The *lumbocostal arches* are tendinous arches, one of which extends from the body to the transverse process of the first or second lumbar vertebra; the other extends from the transverse process of the first lumbar vertebra to the last rib.

crura.[10] The fibers converge toward the central portion which is aponeurotic, and serves for the insertion of the muscular portion.

The diaphragm has three large openings: the esophageal, for the passage of the esophagus, some esophageal arteries, and the vagus nerves; the aortic, for the passage of the aorta, the azygos vein, and the thoracic duct (strictly speaking, behind the diaphragm); the vena caval, for the passage of the inferior vena cava and some branches of the right phrenic nerves. The upper or thoracic surface of the diaphragm is highly arched; the heart is supported by the central tendinous portion of the arch, the right and left lungs by the lateral portions, the right portion of the arch being slightly higher than the left. The lower or under surface of the diaphragm is deeply concave, and covers the liver, stomach, pancreas, spleen, and kidneys.

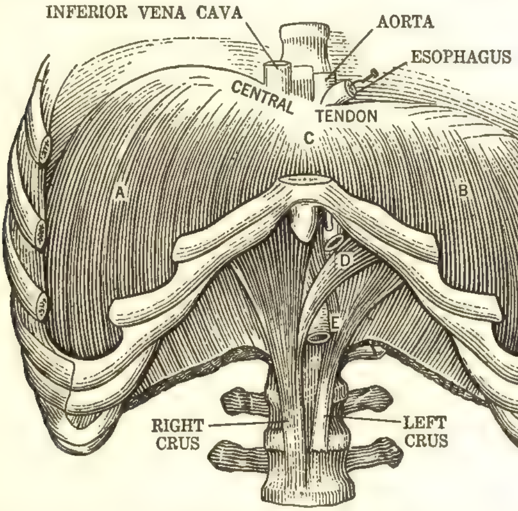


FIG. 90. — DIAPHRAGM. Viewed from in front. At *A* the liver and at *B* the cardiac end of the stomach are underneath the diaphragm and push it up; at *C* the tip of the heart pushes the diaphragm down. At *D* and *E* the esophagus and aorta are shown. (Gerrish.)

Action. — The diaphragm is the principal muscle of inspiration. When the muscular portion contracts, the central tendon is pulled downward, so that the vertical diameter of the thorax is increased.

In forcible acts of expiration, and in efforts of expulsion from the thoracic and abdominal cavities, the diaphragm and all the other muscles which tend to depress the ribs, and those which compress the abdominal cavity, concur in

[10] The *crura* (singular *crus*) are tendinous slips. The right crus arises from the bodies of the upper three lumbar vertebræ and the left from the bodies of the upper two.

powerful action to empty the lungs, to fix the trunk, and to expel the contents of the abdominal viscera. Thus it follows that the action of the diaphragm is of assistance in expelling the fetus from the uterus, the feces from the rectum, the urine from the bladder, and the contents from the stomach in vomiting.

The muscles of the abdomen may be divided into two groups, namely, *antero-lateral* or those which form the front and side walls, and *posterior* or those which form the wall of the back.

Antero-lateral	**Posterior**
External oblique	Psoas major
Internal oblique	Psoas minor
Transversus	Iliacus
Rectus abdominis	Quadratus lumborum
Pyramidalis	

The external or descending oblique (obliquus externus) is the strongest and most superficial of the abdominal muscles. It arises from the external surface of the lower eight ribs. The fibers from the lowest ribs pass downward and are inserted into the anterior half of the iliac crest, the middle and the upper fibers pass downward and forward and terminate in the broad aponeurosis, which, meeting its fellow of the opposite side in the linea alba, covers the whole of the front of the abdomen. Between the anterior superior iliac spine and the pubic tubercle [11] the aponeurosis forms a thick band which is called the inguinal ligament (Poupart's [12] ligament).

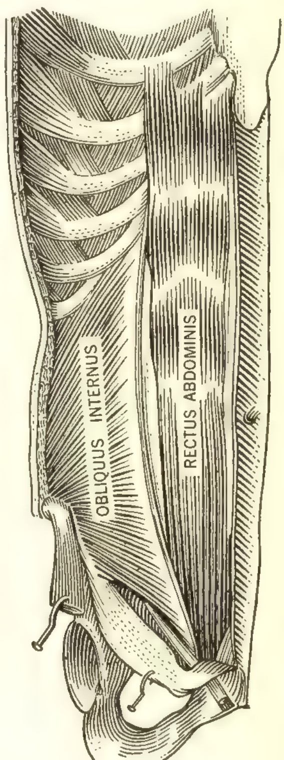


FIG. 91. — RECTUS ABDOMINIS AND OBLIQUUS INTERNUS OF RIGHT SIDE. (Gerrish.)

The internal or ascending oblique (obliquus internus) lies just beneath the external oblique. It arises from the inguinal ligament, the crest of the ilium, and the lumbodorsal fascia. The fibers are inserted into the costal cartilages of the lower six ribs, the linea alba (by means of an aponeurosis), and the crest of the pubis. At the lateral border of the rectus the aponeurosis divides into two layers which continue forward, one in front and the other behind the rectus muscle; they reunite at the linea alba and thus form a sheath for the rectus.

[11] The pubic tubercle is a spine of bone which projects from the upper border of the body of the pubis.

[12] François Poupart, French anatomist, 1661–1709.

The transversus (transversalis) muscle is just beneath the internal oblique. The fibers arise from the lower six costal cartilages, the lumbodorsal fascia, the anterior three-quarters of the iliac crest, and the lateral third of the inguinal ligament. The greater part of its fibers have a horizontal direction, and end in front in a broad aponeurosis which is inserted into the linea alba and the crest of the pubic bone.

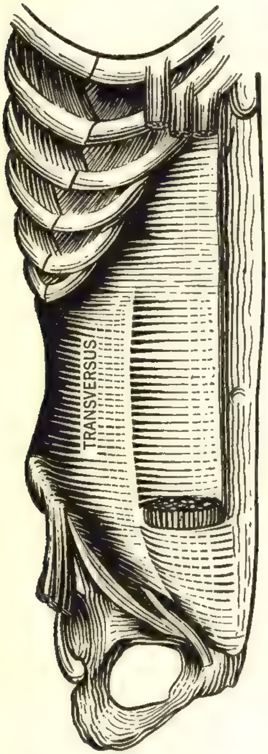


FIG. 92.—TRANSVERSUS (TRANSVERSALIS) OF RIGHT SIDE. (Gerrish.)

The rectus abdominis is a long, flat muscle, consisting of vertical fibers situated at the front part of the abdomen, and enclosed in the fibrous sheath formed by the aponeuroses of the internal oblique, the external oblique, and the transversus muscles. It arises from the pubic bone and the ligaments covering the front of the symphysis pubis and is inserted into the cartilages of the fifth, sixth, and seventh ribs. It is separated from the muscle of the other side by a narrow interval which is occupied by the linea alba.

Action of the abdominal muscles.—When these muscles contract, they compress the abdominal viscera and constrict the cavity of the abdomen, in which action they are much assisted by the descent of the diaphragm. By these means they give assistance in parturition, defecation, micturition, and emesis. They also assist in expiration and bend the thorax forward. When the muscles of only one side contract, the trunk is bent toward that side.

The linea alba is a tendinous line in the middle of the abdomen formed by the blending of the aponeuroses of the two oblique and the transversus muscles of both sides. It stretches from the xiphoid process to the symphysis pubis. It is a little broader above than below, and a little below the middle it is widened into a flat, circular space, in the center of which is situated the umbilicus.

The pyramidalis arises from the front of the pubis and is inserted into the linea alba halfway between the umbilicus and the pubis. It is in front of the rectus, within the same sheath.

Action. — Contraction of the pyramidalis increases the tension of the linea alba.

The inguinal canal. — Parallel to, and a little above, the inguinal ligament is a tiny canal, about 4 cm. ($1\frac{1}{2}$ in.) long, called the inguinal canal. The internal opening of the canal is called the *abdominal inguinal ring,* and is situated in the fascia of the transversus muscle, half way between the anterior superior spine of the ilium and the symphysis pubis. The canal ends in the *subcutaneous inguinal ring,* which is an opening in the tendon of the external oblique just above and lateral to the crest of the pubis. This canal transmits the spermatic cord in the male, and the round ligament of the uterus in the female.

Weak places in the abdominal walls. — The abdominal inguinal and the subcutaneous inguinal rings, described above, the *umbilicus,* and another ring situated just behind the inguinal ligament, called the *femoral ring,* are considered weak places because they are so often the seat of *hernia.*

Hernia,[13] or rupture, is a protrusion of a portion of the contents of a body cavity, and in this instance would mean a protrusion of a portion of the intestine or mesentery through one of these weak places. If it occurs in the umbilicus, it is called *umbilical hernia;* in the inguinal rings, *inguinal hernia;* and in the femoral ring, *femoral hernia.* Conditions which favor hernia are (1) lifting, coughing, etc., which greatly increase the pressure of the abdominal contents against the body wall, and (2) lack of tone of the ventral abdominal wall which comes about in old age, or as the result of illness. The inguinal canal is larger in the male than in the female, hence inguinal hernia is more common in the male than in the female. There are other abdominal hernias.

The psoas major, the psoas minor, and the iliacus are described with the muscles of the lower extremities.

The quadratus lumborum. — The quadratus lumborum arises from the posterior part of the crest of the ilium and the iliolumbar ligament,[14] and is inserted into the lower border of the twelfth rib and the transverse processes of the upper four lumbar vertebræ. The colon, the kidney, the psoas major and minor are in front of the quadratus lumborum.

Action. — The quadratus lumborum acts as a muscle of inspiration by helping to hold the outer edge of the diaphragm steady.

Muscles of the Pelvis	Hip-joint	Obturator internus. Obturator externus.
	Pelvic diaphragm	Levator ani. Coccygeus.

[13] If the skull is injured so that a portion of the brain protrudes, it would also be correctly spoken of as hernia of the brain. Of course this is more unusual than abdominal hernia.

[14] The iliolumbar ligament connects the pelvis with the vertebral column.

The hip-joint muscles will be described with the muscles of the lower extremities. They are partly in the pelvis and partly at the back of the hip-joint.

The levator ani is a broad, thin muscle which is attached to the inner surface of the lesser pelvis. It arises in front from the posterior surface of the body of the pubic bone, behind from the spine of the ischium and the obturator fascia which extends between these two points. The insertion posteriorly is in the side of the coccyx and a median fibrous band which extends between the coccyx and the anus. The middle fibers are inserted in the rectum and the anterior fibers in the perineum.

The coccygeus is behind the levator ani. It arises from the spine of the ischium and is inserted into the coccyx and the sides of the sacrum.

Action. — These muscles form a floor which supports the pelvic viscera. The levator ani constricts the lower end of the rectum and vagina.

MUSCLES OF THE UPPER EXTREMITIES

A certain number of muscles situated superficially on the trunk are frequently grouped with the muscles of the upper extremities, as their function is to attach the upper limbs to the trunk and move the shoulders and arms. Of these, the chief are the two superficial muscles, trapezius and latissimus dorsi we have mentioned as covering the back, and the pectoralis major and pectoralis minor covering the front of the chest.

We may group the muscles of the upper extremities as follows:

Muscles connecting the upper extremity to the vertebral column	Trapezius. Latissimus dorsi. Rhomboideus major. Rhomboideus minor. Levator scapulæ.

The rhomboideus major arises from the upper five thoracic vertebræ and is inserted into the vertebral border of the scapula between the root of the spine and the inferior angle.

The rhomboideus minor arises from the lower part of the ligamentum nuchæ and from the spinous processes of the last cervical and the first thoracic vertebræ. It is inserted into the vertebræ border of the scapula at the root of the spine.

Action. — The rhomboidei carry the inferior angle of the scapula upward and produce a slight rotation.

The levator scapulæ arises from the upper four or five cervical vertebræ. It is inserted into the vertebral border of the scapula between the superior angle and the root of the spine.

Action. — As the name suggests, it lifts the angle of the scapula.

Muscles connecting the upper extremity to the anterior and lateral thoracic walls.	Pectoralis major. Pectoralis minor. Serratus anterior. Subclavius.

The first three have been described.

The subclavius arises from the junction of the first rib and its cartilage and is inserted into a groove on the under surface of the clavicle.

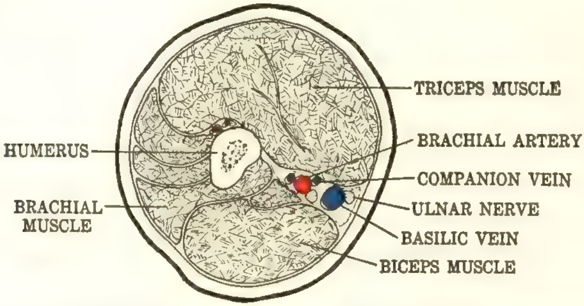


FIG. 93. — TRANSVERSE SECTION THROUGH THE MIDDLE OF THE RIGHT UPPER ARM.

Action. — The subclavius depresses the shoulder, *i.e.*, carries it downward and forward.

Muscles of the shoulder	Deltoid. Subscapularis. Supraspinatus. Infraspinatus. Teres minor. Teres major.

The deltoid (deltoideus) is a thick triangular muscle which covers the shoulder joint. It arises from the clavicle, the acromion process and spine of the scapula, and is inserted into the lateral side of the body of the humerus.

Action. — It abducts — raises the arm from the side, so as to bring it at right angles to the trunk.

The other five shoulder muscles listed in the table may be found in the summary and may be located on Figs. 94 and 95.

Muscles of the arm	Biceps brachii. Triceps brachii. Coracobrachialis. Brachialis.

The biceps (biceps brachii) arises by two heads, hence its name. The long head arises from a tuberosity at the upper margin of the glenoid cavity, and the short head from the coracoid process in common with the coracobrachialis muscle. (See Fig. 94.) These tendons are succeeded by elongated bodies which are separate until within a short distance (7 cm.) of the elbow joint, where they

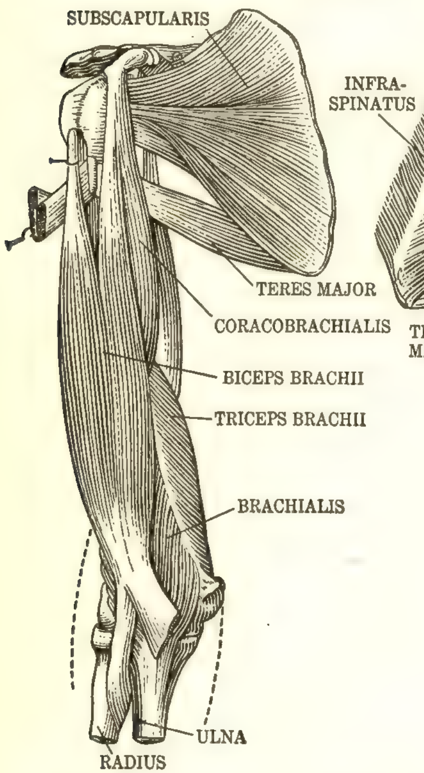


FIG. 94. — MUSCLES OF THE FRONT OF THE RIGHT SHOULDER AND ARM.

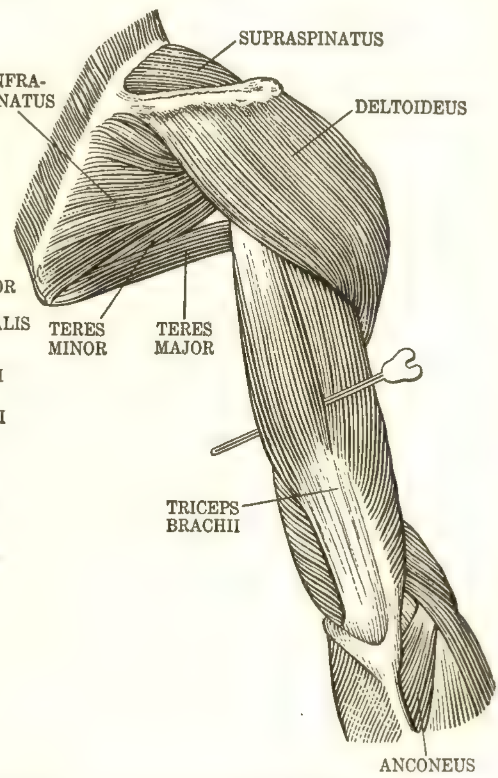


FIG. 95. — MUSCLES OF THE DORSUM OF THE RIGHT SHOULDER AND ARM. (Gerrish.)

unite and terminate in a flat tendon, which is inserted into the tuberosity of the radius.

Action. — It causes flexion of the elbow and to a less extent of the shoulder, also *supination* of the hand.

The triceps (triceps brachii) arises by three heads, the long head from the infraglenoid tuberosity of the scapula, and the lateral and medial heads from the posterior surface of the body of the humerus, the lateral head above the medial. The muscle fibers

terminate in two aponeurotic laminæ, which unite above the elbow and are inserted into the olecranon of the ulna.

Action. — The triceps is the great extensor muscle of the forearm, and is the direct antagonist of the biceps.

The coracobrachialis and brachialis are included in the summary.

Muscles of the forearm. — The forearm muscles are called *antibrachial,* and are divided into a volar[15] and a dorsal group. The volar group is further subdivided into a superficial and deep group.

Superficial Group

Pronator teres
Flexor carpi radialis
Palmaris longus
Flexor carpi ulnaris
Flexor digitorum sublimus

Deep Group

Flexor digitorum profundus
Flexor pollicis longus
Pronator quadratus

These muscles arise from the medial epicondyle of the humerus and from the anterior surface of the radius and ulna near the elbow joint. They are inserted into the body of the radius, the carpals, metacarpals, phalanges, and the aponeurosis of the palm of the hand. For details consult summary at the end of the chapter.

The dorsal group is also divided into a superficial and a deep group.

Superficial Group

Brachioradialis
Extensor carpi radialis longus
Extensor carpi radialis brevis
Extensor digitorum communis
Extensor digiti quinti proprius
Extensor carpi ulnaris
Anconeus

Deep Group

Supinator
Abductor pollicis longus
Extensor pollicis brevis
Extensor pollicis longus
Extensor indicis proprius

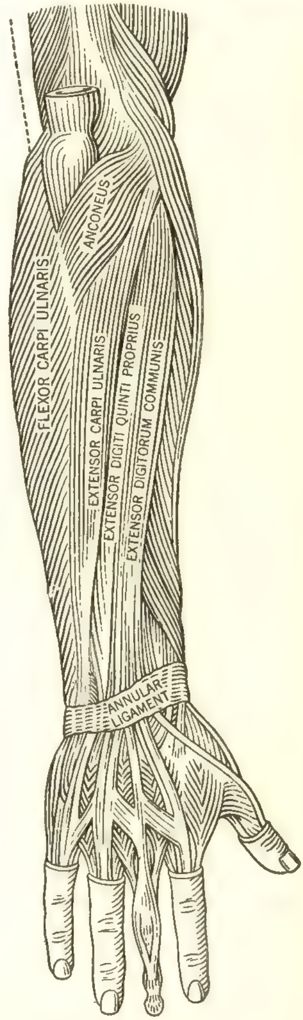


FIG. 96. — MUSCLES IN THE DORSUM OF THE RIGHT FOREARM AND HAND. (Gerrish.)

[15] Volar, pertaining to the palm or sole.

These muscles arise from the lateral epicondyle of the humerus and the posterior surface of the ulna and radius. They are inserted into the body of the radius, the metacarpals, and phalanges.

Action. — They extend the elbow, extend, adduct, and abduct the wrist, extend the fingers, and supinate the hand.

The muscles of the hand are divided into three groups: (1) the *lateral volar*, or thumb muscles, which are located on the radial side and form the thenar eminence, (2) the *medial volar*, or little finger muscles, which are located on the ulnar side and form the hypothenar eminence, and (3) the intermediate muscles, located in the middle of the palm and between the metacarpal bones.

Action. — These muscles act upon the thumb and fingers.

MUSCLES OF THE LOWER EXTREMITIES

If the muscles of the shoulder, arm, and forearm are compared with those of the hip, thigh, and leg, it will be noted that the anterior muscles of the former correspond roughly with the posterior muscles of the latter, the muscles of the hip, thigh, and leg, however, being larger and coarser in texture than those of the shoulder, arm, and forearm.

Muscles of the iliac region { Psoas major. Psoas minor. Iliacus.

The psoas major (magnus) arises from the transverse processes of the last thoracic and all the lumbar vertebræ with the included intervertebral cartilages. It extends downward and forward, then downward and backward, to its insertion in the small trochanter of the femur.

The psoas minor arises from the bodies of the twelfth thoracic and first lumbar vertebræ and is inserted into the pectineal line and iliac fossa.

The iliacus arises from the iliac fossa. The fibers converge and are inserted into the lateral side of the tendon of the psoas major and the body of the femur below and in front of the lesser trochanter. The relation of this muscle to the psoas major is well shown in Fig. 97.

Action. — The psoas major and iliacus act as one muscle to flex the thigh on the pelvis, and rotate the femur outward. The psoas minor is a tensor of the iliac fascia.

Muscles of the gluteal region
- Gluteus maximus.
- Gluteus medius.
- Gluteus minimus.
- Tensor fasciæ latæ.
- Piriformis.
- Obturator internus.
- Obturator externus.

The gluteus maximus arises from the posterior fourth of the iliac crest, the posterior surface of the lower part of the sacrum, the

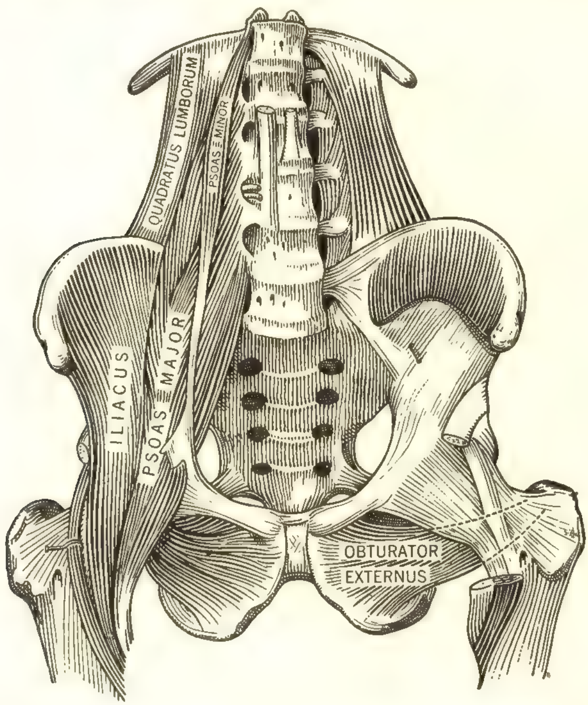


FIG. 97. — PSOAS, ILIACUS, AND OBTURATOR EXTERNUS MUSCLES. (Gerrish).

side of the coccyx, and the aponeuroses of the sacrospinalis and the gluteus medius. It is inserted into the fascia lata and the upper part of the linea aspera of the femur. The thigh muscles are covered by a heavy cylindrical fascia — the fascia lata — which extends from the highest margin of the thigh to the bony prominences around the knee and helps to form the capsular ligament of the knee joint. It varies in thickness in different parts. In the region of the gluteus maximus and the tensor fasciæ latæ it splits into two layers, which surround each of these muscles.

Action. — It extends the femur and adducts it.

The gluteus medius and gluteus minimus are under the gluteus maximus and almost entirely covered by it. They arise from the outer surface of the ilium and are inserted into the great trochanter.

Action. — It causes abduction of the thigh, and inward rotation.

The tensor fasciæ latæ arises from the anterior part of the iliac crest and is inserted between the layers of the fascia lata at a point about one-third of the way down the thigh.

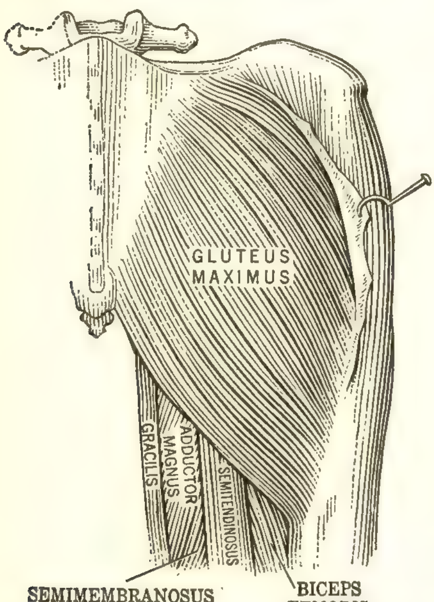


Fig. 98. — Diagram of Gluteus Maximus Muscle of Right Side. (Gerrish.)

Action. — It causes tightening of the fascia lata, abduction and inward rotation of the thigh.

The piriformis arises from the anterior surface of the sacrum and passes out of the pelvis to be inserted into the upper border of the great trochanter. (See Fig. 101.)

Action. — It supports the floor of the pelvis and rotates the thigh outward.

The obturator internus arises from the inner surface of the anterolateral wall of the pelvis, the greater part of the obturator foramen, and the pelvic surface of the obturator membrane.[16] It is inserted in the fore part of the medial surface of the greater trochanter. (See Fig. 101.)

Action. — It brings about external rotation of the thigh.

The obturator externus arises from the margin of bone around the obturator foramen and from the outer surface of the obturator membrane. The fibers of this muscle end in a tendon, which is inserted into a fossa at the base of the great trochanter (trochanteric fossa).

Action. — It supports the floor of the pelvis and rotates the thigh outward.

[16] The obturator membrane is a fibrous sheet which almost completely closes the obturator foramen.

Anterior Femoral Muscles { Sartorius
Quadriceps Femoris { Rectus femoris.
Vastus lateralis.
Vastus medialis.
Vastus intermedius.

The sartorius arises from the anterior superior spine of the ilium and is inserted into the upper part of the medial surface of the body of the tibia.

Action. — It flexes the leg upon the thigh, and the thigh upon the pelvis, also rotates the thigh outward.

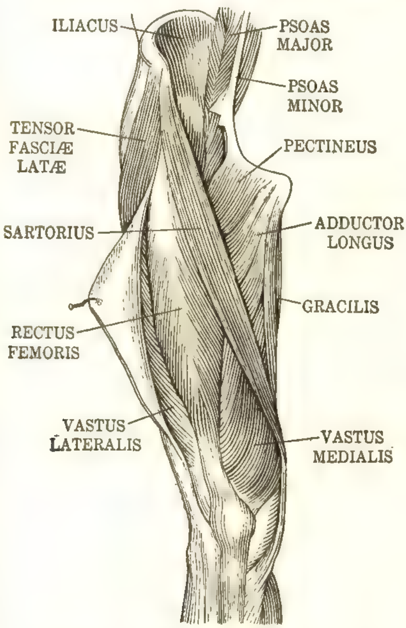


FIG. 99. — SUPERFICIAL MUSCLES IN FRONT PART OF THE RIGHT THIGH. (Gerrish.)

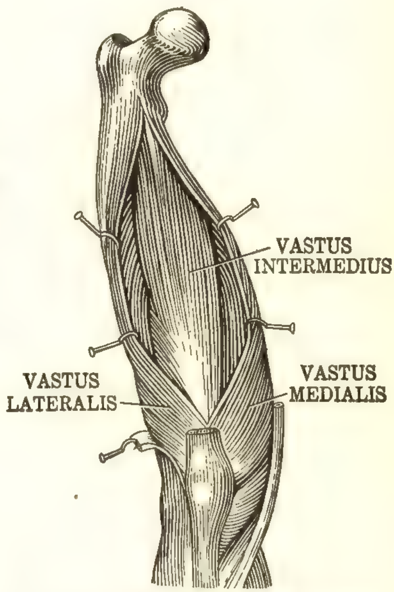


FIG. 100. — VASTUS INTERMEDIUS OF RIGHT THIGH. (Gerrish.)

The quadriceps femoris (quadriceps extensor) is a four-headed muscle that covers the front and sides of the thigh. Each head is described as a separate muscle.

The rectus femoris arises by two tendons, one from the anterior inferior iliac spine, the other from a groove above the brim of the acetabulum.

The vastus lateralis (vastus externus) arises by a broad aponeurosis from the great trochanter and the linea aspera of the femur.

The vastus medialis (vastus internus) arises from the medial lip of the linea aspera.

The vastus intermedius (crureus) arises from the ventral and lateral surfaces of the body of the femur.

The fibers of these four muscles unite at the *lower* part of the thigh and form a strong tendon, which is inserted into the tuberosity of the tibia. The tendon passes in front of the knee joint, and the patella is a sesamoid bone developed in it.

Action. — The quadriceps femoris extends the leg upon the thigh, and the rectus portion flexes the thigh.

The Medial Femoral Muscles
- Gracilis.
- Adductor longus.
- Adductor brevis.
- Adductor magnus.

The gracilis arises from the symphysis pubis and the pubic arch and is inserted into the medial surface of the tibia.

The adductor longus arises from the front of the pubis and is inserted into the linea aspera of the femur.

The adductor brevis arises from the outer surfaces of the superior and inferior rami of the pubis, and is inserted into the upper part of the linea aspera.

The adductor magnus arises from the inferior ramus of the pubis and the tuberosity of the ischium, and is inserted into the linea aspera.

Action. — The gracilis adducts the thigh and flexes the leg. The longus, brevis, and magnus adduct, flex, and rotate the thigh outward.

Posterior Femoral Muscles
- Biceps femoris.
- Semitendinosus.
- Semimembranosus.

The biceps femoris arises by two heads, the long head from the tuberosity of the ischium and the short head from the linea aspera of the femur. It is inserted into the lateral side of the head of the fibula and the lateral condyle of the tibia.

The semitendinosus arises from the tuberosity of the ischium and is inserted into the upper part of the medial surface of the body of the tibia.

The semimembranosus arises from the tuberosity of the ischium and is inserted on the medial condyle of the tibia.

The tendons of insertion of these muscles are called the hamstrings, hence the muscles are often called the hamstring muscles.

Action. — They flex the leg upon the thigh, and extend the thigh. When the knee is flexed, the semitendinosus and semimembranosus rotate the leg inward.

The muscles of the leg may be divided into three groups.

Anterior	Posterior	
	Superficial	*Deep*
Tibialis anterior	Gastrocnemius	Popliteus
Extensor hallucis longus	Soleus	Flexor hallucis longus
Extensor digitorum longus	Plantaris	Flexor digitorum longus
		Tibialis posterior

Lateral

Peroneus longus
Peroneus brevis

The tibialis anterior (anticus) arises from the lateral condyle and upper portion of the lateral surface of the body of the tibia, and is inserted into the under surface of the first cuneiform bone and the base of the first metatarsal.

Action. — It flexes the foot at the ankle joint, and with the tibialis posterior raises the medial border of the foot, or inverts the foot.

The extensor hallucis longus arises from the anterior surface of the fibula, and is inserted into the distal phalanx of the great toe.

The extensor digitorum longus arises from the lateral condyle of the tibia and the upper portion of the anterior surface of the fibula. The terminal tendon divides into four slips, which are inserted into the second and third phalanges of the four lesser toes. A fifth tendon of this muscle is sometimes described as the *peroneus tertius* muscle.

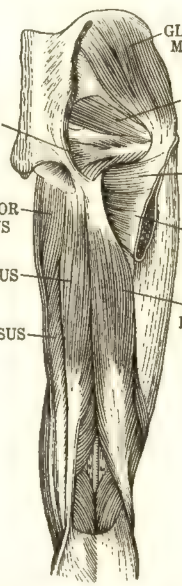


FIG. 101. — MUSCLES IN THE DORSUM OF THE RIGHT THIGH. (Gerrish.)

Action. — The two extensor muscles extend the phalanges of the toes and flex the foot upon the leg.

The gastrocnemius and *soleus* form the calf of the leg. The gastrocnemius arises by two heads from the medial and lateral condyles of the femur. The soleus arises from the back of the head of the fibula and the medial border of the tibia. The direction of both is downward, and they are inserted into a common tendon, the

tendo calcaneus (tendo Achillis), which is the thickest and strongest tendon in the body, and is inserted into the calcaneus, or heel bone.

Action. — The gastrocnemius and soleus extend the foot at the ankle joint, and the gastrocnemius flexes the femur upon the tibia.

The plantaris arises from the linea aspera of the femur and the popliteal ligament of the knee joint and is inserted into the calcaneus. It is between the gastrocnemius and the soleus.

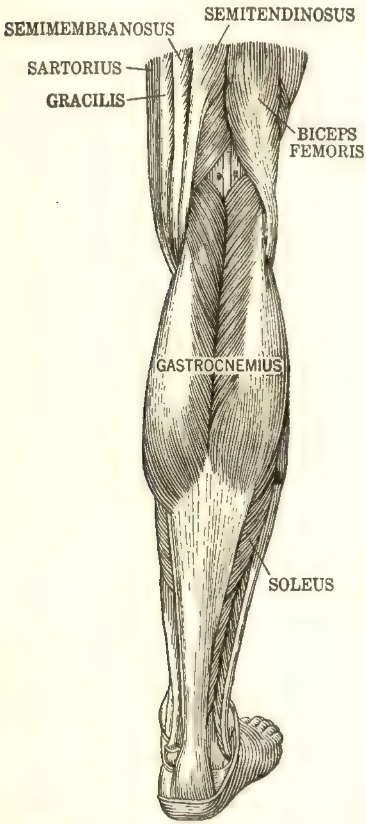


FIG. 102. — GASTROCNEMIUS OF RIGHT SIDE. (Gerrish.)

Action. — The plantaris is an accessory to the gastrocnemius.

The popliteus arises from the lateral condyle of the femur, and is inserted into the posterior surface of the body of the tibia.

Action. — The popliteus assists in flexing the leg upon the thigh and rotates the tibia outward.

The flexor hallucis longus arises from the posterior surface of the body of the tibia, and is inserted into the base of the last phalanx of the great toe.

The flexor digitorum longus arises from the posterior surface of the body of the tibia, and is inserted by four tendons into the bases of the last phalanges of the four lesser toes.

Action. — The flexor hallucis longus and the flexor digitorum longus flex the phalanges and extend the foot.

The tibialis posterior (posticus) arises from the aponeurotic septum, between the tibia and the fibula, and from the adjoining parts of these two bones. It is inserted into the under surface of the navicular bone, and gives off fibers which are attached to the calcaneus, the three cuneiforms, the cuboid, and the second, third, and fourth metatarsal bones.

Action. — It extends the foot at the ankle joint. Acting with the tibialis anterior, it inverts the foot, *i.e.*, turns the sole of the foot upward and medialward.

The peroneus longus arises from the head and the lateral surface of the body of the fibula. The terminal tendon passes under the cuboid bone, crosses the sole of the foot obliquely, and is inserted into the lateral side of the first metatarsal and first cuneiform bones.

Action. — It extends and everts the foot and helps to maintain the transverse arch.

The peroneus brevis arises from the lower portion of the lateral surface of the body of the fibula, and is inserted into the fifth metatarsal bone.

Action. — It extends the foot.

The muscles of the foot are divided into dorsal and plantar. Many of the leg muscles are connected with the foot and act with the dorsal and plantar muscles in maintaining the arches of the foot.

SUMMARY

The movements of the body are dependent upon the contractions of muscular tissue.

Correlated Systems	Skeletal System. Muscular System. Nervous System.
Characteristics of Muscular Tissue	1. Irritability or excitability — property of receiving stimuli and responding to them. 2. Contractility — muscle becomes shorter, thicker, because each cell does. 3. Extensibility — muscle can be stretched, *i.e.*, property of individual cells. 4. Elasticity — muscle readily returns to original shape.
Tone	Mild, sustained contraction existing under normal conditions. Skeletal muscles — stimuli from central nervous system. Visceral muscle preëminent in power to show tone. Satisfactory blood-pressure and healthy digestion dependent on it. Visceral tone depends upon: 1. Substances in blood. 2. Secretions from ductless glands. 3. Stimuli from nervous system.
Classification	1. Striated, skeletal. 2. Non-striated, visceral. 3. Indistinctly striated, cardiac.
Muscular Tissue	Cells become elongated and are called fibers. Intercellular substance is at a minimum. Connective tissue — supporting framework. Well supplied with nerves and blood-vessels.

Striated — Cross-striped; Skeletal

1. Marked with transverse striæ.
2. Movements accomplished by it are voluntary.
3. Attached to skeleton.
4. Muscle cells are long and spindle-shaped.
5. Connective tissue framework carries blood-vessels and nerves.
6. Origin — more fixed attachment.
7. Insertion — more movable attachment.
8. Origin in periosteum of bone or intervening tendon.
9. Insertion either by tendons or aponeuroses.
10. Muscles closely covered by sheets of fasciæ.
11. Deep fasciæ form annular ligaments in vicinity of wrist and ankle.

Function. — To operate the bones of the body producing motion.

Non-striated — Smooth; Visceral

1. Not marked with transverse striæ.
2. Movements accomplished by it are involuntary.
3. Found in walls of blood-vessels and viscera.
4. Composed of spindle-shaped cells that contain one large nucleus.
5. Connective tissue framework carries blood-vessels and nerves.

Function. — To cause visceral motion.

Cardiac — Striated; Involuntary; Visceral

1. Striated, but not distinctly.
2. Not under control of will.
3. Cells are quadrangular in shape.
4. Cells grouped in bundles.
5. Connective tissue forms a supporting framework.

Stimuli
- Term used to describe influences which affect excitability of muscles.
- Normally muscles are stimulated by nerves.

Nerves
- Afferent — Carry impulses from periphery *to* brain, spinal cord, or ganglia. Afferent nerves connected with muscle are spoken of as sensory.
- Efferent — Carry impulses to the periphery *from* brain, spinal cord, or ganglia. Efferent nerves that end in muscles are spoken of as motor.

Varieties of Muscular Movements
- Voluntary — stimuli from central nervous system.
- Involuntary, Cardiac — Stimuli from nervous system increase or decrease activity.

Conditions of Contraction
- Skeletal muscle — contracts quickly, relaxes promptly.
- Visceral muscle — contracts slowly, maintained for some time, fades out slowly.
- Heart muscle — refractory period long.
- Contractions
  - Result of series of rhythmic stimuli.
  - Consist of latent period, contraction period, relaxation period.
- Tetanus — compound contraction, due to stimuli being received too rapidly to allow for periods of relaxation. Heart muscle does not exhibit absolute tetanic contractions due to long refractory period.

Source of Energy

- Well supplied with blood from which oxygen is obtained.
- Well supplied with blood from which glucose is obtained and stored as glycogen.
- *Glycogen* represents chemical energy.
- Characteristic muscle phosphates undergo chemical changes yielding energy for contraction.
- Glycogen is broken down to lactic acid yielding energy for reconstitution of the muscle phosphates.
- Some lactic acid is oxidized to carbon dioxide and water yielding energy.
- About $\frac{4}{5}$ of the lactic acid is resynthesized to glycogen.
- During contraction and relaxation
  - Oxygen is used.
  - Carbon dioxide is produced.
  - Glycogen is used.
  - Lactic acid is produced.
  - Some lactic acid is oxidized.
  - Some lactic acid is reformed to glycogen.
  - Muscle phosphates undergo reversible changes.

Fatigue

- Loss of nutritive materials.
- Accumulation of waste substances.

FUNCTIONALLY IMPORTANT MUSCLES

Name of Muscle			Origin	Insertion	Function
Muscles of Head	Epicranial or Occipito-frontalis	Occipital	Occipital bone	Aponeurosis — top of skull	Draws the scalp backward.
		Frontal	Aponeurosis — top of skull	Tissues of the eyebrows	Elevates the eyebrows, causes transverse wrinkles of forehead.
Muscles of the Orbit and Eyelids	*Face*				
	Superior rectus		Apex of orbit	Upper and central portion of eyeball	Rolls the eyeball upward.
	Inferior rectus		Apex of orbit	Lower and central portion of eyeball	Rolls the eyeball downward.
	Medial rectus		Apex of orbit	Midway on inner side of eyeball	Rolls the eyeball to which it is attached inward, the opposite one outward.
	Lateral rectus		Apex of orbit	Midway on outer side of eyeball	Rolls the eyeball to which it is attached outward, the opposite one inward.
	Superior oblique		Apex of orbit	Eyeball — between superior and lateral recti	Rotates eyeball on its axis, directs cornea downward and lateralward.
	Inferior oblique		Orbital plate of the maxilla	Eyeball — near lateral recti	Rotates eyeball on its axis, directs cornea upward and lateralward.
	Levator palpebræ superioris		Apex of orbit	Tarsal cartilage of upper lid	Elevates upper lid and opens eye.
	Orbicularis oculi		Nasal portion of frontal bone, frontal process of maxilla and a short fibrous band the medial palpebral ligament	Palpebral portion is inserted into lateral palpebral raphe Orbital portion surrounds orbit — upper fibers blend with the frontalis muscle	Palpebral portion closes the lids as in blinking. This action is involuntary. Entire muscle closes lids forcibly.

Name of Muscle		Origin	Insertion	Function
Muscles of Mastication	Masseter	Zygomatic process and adjacent portions of maxilla	Ramus of mandible	Raises the mandible and closes the mouth.
	Temporal	Temporal fossa	Coronoid process of mandible	Raises the mandible and closes the mouth. Draws the mandible backward.
	Internal pterygoid	Pterygoid plate, palatine and maxilla	Ramus of mandible	Raises the mandible and closes the mouth.
	External pterygoid	Sphenoid bone and pterygoid plate	Condyle of mandible	Moves the jaw forward and sideways. Helps to open the mouth.
Muscles of the Lips	Orbicularis Oris	Facial muscles and partition between nostrils and maxillæ	Lips and mandible	Closes the lips. Sphincter of mouth.
	Buccinator	Alveolar processes of maxilla and mandible	Orbicularis oris	Compresses the cheeks, brings them in contact with the teeth.
Muscles of the Tongue	Genioglossus	Symphysis of mandible	Hyoid bone and under surface of tongue	Thrusts the tongue forward, retracts it, and also depresses it.
	Styloglossus	Styloid process of temporal bone	Whole length of side and under part of tongue	Draws the tongue upward and backward.
Muscles of the Neck	Platysma	Skin and fascia of the pectoral and deltoid muscles	Mandible and muscles about the angle of the mouth	Depresses the mandible, and draws down the lower lip.
	Sternocleidomastoid	Sternum and clavicle	Mastoid portion of temporal bone	Each muscle acting alone draws the head toward shoulder of same side. Both acting together flex the head on the chest or neck.

	Name of Muscle	Origin	Insertion	Function
Muscles of the Back	Trapezius	Occipital bone, ligamentum nuchæ, spinous process of the seventh cervical and the spinous processes of twelve thoracic vertebræ	Clavicle, acromion process, and spine of scapula	If upper end is fixed, shoulder is raised. If shoulders are fixed, both muscles draw head backward. Contraction of whole muscle retracts the scapula and braces back the shoulder. Lower fibers help to depress scapula.
	Latissimus dorsi	Lower six thoracic vertebræ, lumbar and sacral vertebræ, crest of ilium and lower three or four ribs	Intertubercular groove of humerus	Depresses the humerus, draws it backward, and rotates it inward.
	Sacrospinalis Lateral column Iliocostalis { lumborum, dorsi, cervicis Intermediate column Longissimus { dorsi, cervicis, capitis Medial column Spinalis { dorsi, cervicis, capitis	Lower and posterior part of sacrum, posterior portion of iliac crests, spines of the lumbar and lower two thoracic vertebræ	Series of attachments to ribs and vertebræ all the way up the back to the occipital bone and mastoid process of temporal bone.	Serves to maintain the vertebral column in the erect posture.

Name of Muscle		Origin	Insertion	Function
Muscles of the Chest	Pectoralis major	Clavicle, sternum, cartilages of true ribs and external oblique	Greater tubercle of humerus	It adducts and draws the arm across the chest, also rotates it inward.
	Pectoralis minor	Upper margins and outer surfaces of 3d, 4th, and 5th ribs	Coracoid process of scapula	Depresses the shoulder and rotates the scapula downward.
	Serratus anterior	Surfaces and superior borders of upper eight or nine ribs	Various portions of the ventral surface of scapula	Carries scapula forward and raises vertebral border as in pushing. Assists deltoid in raising the arm.
Muscles of the Thorax	External intercostals	Arise from lower border of a rib	Upper border of rib below.	Contract simultaneously and prevent intercostal spaces from being pushed outward or drawn inward. May be inspiratory muscles.
	Internal intercostals	Arise from inner surface of a rib	Upper border of rib below.	
	Levatores costarum	Transverse processes of vertebræ from 7th cervical to the 11th thoracic	Outer surface of the rib just below vertebra from which it arises	Act as rotators and lateral flexors of the vertebral column. May be inspiratory muscles.
	Diaphragm	Lower circumference of the thorax.	A central aponeurotic tendon	Principal muscle of inspiration, modifies size of chest and abdominal cavity. Aids in expulsion.

Name of Muscle		Origin	Insertion	Function
Muscles forming antero-lateral walls of abdomen	External or descending oblique	External surface of lower eight ribs	Anterior half of iliac crest and broad aponeurosis, meeting its fellow of opposite side in linea alba	Compresses the abdominal viscera.
	Internal or ascending oblique	Inguinal ligament, crest of the ilium, and the lumbodorsal fascia	Costal cartilages of lower six ribs, linea alba, and crest of pubis	Compresses the abdominal viscera.
	Transversus	Lower six costal cartilages, lumbodorsal fascia, iliac crest, and lateral third of the inguinal ligament	Linea alba and crest of the pubis	Compresses the abdominal viscera.
	Rectus abdominis	Pubic bone and ligaments covering front of symphysis pubis	Costal cartilages of 5th, 6th, and 7th ribs	Compresses the abdominal viscera.
	Pyramidalis	Front of pubis	Inserted into linea alba between umbilicus and pubis	Increases tension of the linea alba.

Name of Muscle			Origin	Insertion	Function
Muscles forming the posterior wall of abdomen.		Psoas major	Transverse processes of last thoracic and all the lumbar vertebræ	Small trochanter of femur	Flexes thigh on pelvis, rotates femur outward.
		Psoas minor	Bodies of twelfth thoracic and first lumbar vertebræ	Pectineal line and iliac fossa	Tensor of the iliac fascia.
		Iliacus	Iliac fossa	Tendon of the psoas major and body of the femur	Acts with psoas major.
		Quadratus lumborum	Iliac crest and the iliolumbar ligament	Twelfth rib and transverse processes of four upper lumbar vertebræ	Acts as a muscle of inspiration by holding outer edge of diaphragm steady.
Muscles of the Pelvis	Hip-joint	Obturator Internus	Inner surface of anterolateral wall of obturator foramen and obturator membrane	Fore part of medial surface of greater trochanter	External rotation of thigh.
		Obturator Externus	Margin of bone around the obturator foramen and obturator membrane	Tendinous insertion into trochanteric fossa	Supports floor of pelvis. External rotation of thigh.
	Pelvic Diaphragm	Levator Ani	Posterior surface of body of pubic bone, spine of ischium and obturator fascia	Side of the coccyx and a fibrous band which extends between the coccyx and anus	Helps to form pelvic floor. Constricts the lower end of rectum and vagina.
		Coccygeus	Spine of the ischium	Coccyx and the sides of the sacrum	Helps to form pelvic floor.

Name of Muscle		Origin	Insertion	Function
Muscles connecting the upper extremities to vertebral column	Trapezius Latissimus dorsi	See page 140		
	Rhomboideus major	Upper five thoracic vertebræ	Vertebral border of scapula	Carry the inferior angle of the scapula upward and produce slight rotation.
	Rhomboideus minor	Ligamentum nuchæ and spinous processes of last cervical and first thoracic vertebræ	Vertebral border of scapula	
	Levator scapulæ	Cervical vertebræ	Vertebral border of the scapula	Lifts the angle of the scapula.
Muscles connecting upper extremity to anterior and lateral thoracic wall	Pectoralis major Pectoralis minor Serratus anterior	See page 141		
	Subclavius	Junction of first rib and its cartilage	Groove on under surface of clavicle	Carries the shoulder downward and forward.
Muscles of the Shoulder	Deltoideus	Clavicle, acromion process and spine of scapula	Lateral side of the body of the humerus	Abducts the arm.
	Subscapularis	Subscapular fossa of scapula	Lesser tubercle of humerus	Inward rotation of arm.
	Supraspinatus	Supraspinous fossa of scapula	Greater tubercle of humerus	Abducts the arm.
	Infraspinatus	Infraspinous fossa of scapula	Greater tubercle of humerus	Outward rotation of arm.
	Teres minor	Axillary border of scapula	Greater tubercle of humerus	Outward rotation of arm.
	Teres major	Axillary border of scapula	Intertubercular groove of humerus	Adduction and rotation of arm.

		Name of Muscle	Origin	Insertion	Function
Muscles of the Arm		Biceps brachii	Long head from tuberosity at upper margin of glenoid cavity Short head from coracoid process of scapula	Tuberosity of the radius	Flexes the elbow and supinates the hand.
		Triceps brachii	Long head from infraglenoid tuberosity of scapula, lateral and medial heads from body of humerus	Olecranon of the ulna	Great extensor muscle of forearm.
		Coracobrachialis	Coracoid process of scapula	Mesial border of humerus	Flexes the arm.
		Brachialis	Lower half of front of humerus	Tuberosity of ulna and coronoid process	Flexes the forearm.
Muscles of Forearm Volar Group	Superficial Group	Pronator teres	Humerus and ulna	Body of the radius	Rotates radius upon ulna, renders the hand prone.
		Flexor carpi radialis	Medial epicondyle of humerus	Base of second metacarpal bone	Flexes and abducts the wrist.
		Palmaris longus	Medial epicondyle of humerus	Transverse carpal ligament and palmar aponeurosis	Flexes the wrist joint, assists in flexing the elbow.
		Flexor carpi ulnaris	Humerus and ulna	Pisiform, hamate and fifth metacarpal	Flexor and abductor of wrist, assists in bending elbow.
		Flexor digitorum sublimus	Humerus and radius	Second phalanges of the four fingers	Flexes the middle and proximal phalanges, assists in flexing the wrist and elbow.
	Deep Group	Flexor digitorum profundus	Volar and medial surfaces of body of ulna	Bases of the last phalanges	Flexes the phalanges.
		Flexor pollicis longus	Volar surface of body of radius	Distal phalanx of thumb	Flexes the phalanges of thumb.
		Pronator quadratus	Pronator ridge on body of ulna	Volar surface of body of radius	Rotates the radius upon ulna.

Name of Muscle			Origin	Insertion	Function
Muscles of Forearm Dorsal Group	Superficial Group	Brachioradialis	Supracondylar ridge of humerus	Styloid process of radius	Flexes the elbow joint, assists in bringing hand into supine position.
		Extensor carpi radialis longus	Supracondylar ridge of humerus	Dorsal surface of base of second metacarpal	Extends the wrist and abducts the hand.
		Extensor carpi radialis brevis	Lateral epicondyle of the humerus	Dorsal surface of base of third metacarpal bone	Extends the wrist, may abduct the hand.
		Extensor digitorum communis	Lateral epicondyle of the humerus	Second and third phalanges of fingers	Extends the phalanges, then the wrist, finally the elbow.
		Extensor digiti quinti proprius	From tendon of extensor digitorum communis	Tendon of extensor digitorum communis on dorsum of first phalanx of little finger	Extends the little finger.
		Extensor carpi ulnaris	Lateral epicondyle of humerus and dorsal border of ulna	Ulnar side of fifth metacarpal bone	Extends the wrist.
		Anconeus	Lateral epicondyle of humerus	Side of olecranon and dorsal surface of ulna	Assists the triceps in extending the forearm.
	Deep Group	Supinator	Lateral epicondyle of humerus and radial ligament of elbow joint	Dorsal and lateral surfaces of body of radius	Assists the biceps in bringing hand into supine position.
		Abductor pollicis longus	Dorsal surface of body of ulna	Radial side of base of first metacarpal bone	Carries thumb laterally from the palm of the hand.
		Extensor pollicis brevis	Dorsal surface of body of radius	Base of first phalanx of thumb	Extends proximal phalanx of thumb.
		Extensor pollicis longus	Dorsal surface of body of ulna	Base of last phalanx of thumb	Extends terminal phalanx of thumb.
		Extensor indicis proprius	Dorsal surface of body of ulna	The tendon of extensor digitorum communis	Extends the index finger.

Name of Muscle		Origin	Insertion	Function
Muscles of the Iliac Region	Psoas major Psoas minor Iliacus	See page 143		
Muscles of the Gluteal Region	Gluteus maximus	Iliac crest, sacrum, side of coccyx and aponeurosis of sacrospinalis	Fascia lata and linea aspera of the femur	Extends the femur and abducts it.
	Gluteus medius	Outer surface of ilium and gluteal aponeurosis covering it	Lateral surface of greater trochanter	Abduction of thigh and inward rotation.
	Gluteus minimus	Outer surface of ilium	Anterior border of greater trochanter	Abduction of thigh and inward rotation.
	Tensor fasciæ latæ	Anterior part of iliac crest	About one-third of way down thigh	Tightening of the fascia lata, abduction and inward rotation of thigh.
	Piriformis	Anterior surface of sacrum	Upper border of great trochanter	Supports floor of pelvis, rotates thigh outward.
	Obturator internus Obturator externus	See page 143		
Anterior Femoral Muscles	Sartorius	Anterior superior spine of ilium	Medial surface of the body of the tibia	Flexes the leg upon the thigh and the thigh upon the pelvis.
	Quadriceps femoris arises by four heads: —			
	1. Rectus femoris	Anterior inferior iliac spine and brim of acetabulum		
	2. Vastus lateralis	Great trochanter and linea aspera of femur	Unite and form tendon which is inserted into tuberosity of the tibia	Extends the leg upon the thigh, rectus portion flexes the thigh
	3. Vastus medialis	Medial lip of linea aspera		
	4. Vastus intermedius	Anterior and lateral surfaces of the body of femur		

	Name of Muscle	Origin	Insertion	Function
Medial Femoral Muscles	Gracilis	Symphysis pubis and pubic arch	Medial surface of the tibia	Adducts the thigh, flexes the leg.
	Adductor longus	Front of the pubis	Linea aspera of femur	Adduct, flex, and rotate thigh outward.
	Adductor brevis	Outer surface of superior and inferior rami of pubis	Linea aspera of femur	
	Adductor magnus	Inferior ramus of pubis and tuberosity of the ischium	Linea aspera of femur	
Posterior Femoral Muscles	Biceps femoris	Tuberosity of ischium, linea aspera of femur	Head of the fibula and lateral condyle of tibia	Flex the leg upon the thigh and extend the thigh.
	Semitendinosus	Tuberosity of ischium	Medial surface of body of tibia	
	Semimembranosus	Tuberosity of ischium	Medal condyle of tibia	
Anterior Muscles of Leg	Tibialis anterior	Lateral condyle and upper portion body of tibia	Under surface of first cuneiform and base of first metatarsal	Flexes the foot at the ankle joint and with the tibialis posterior inverts the foot.
	Extensor hallucis longus	Anterior surface of fibula	Distal phalanx of great toe	
	Extensor digitorum longus	Lateral condyle of tibia and anterior surface of fibula	Second and third phalanges of four lesser toes	Extend the phalanges of the toes and flex the foot upon the leg.

Name of Muscle			Origin	Insertion	Function
Posterior Muscles of Leg	Superficial	Gastrocnemius	Medial and lateral condyles of femur	Calcaneus or heel bone	The gastrocnemius flexes the femur upon the tibia. The gastrocnemius and soleus together extend the foot at the ankle joint.
		Soleus	Head of fibula and medial border of tibia		
		Plantaris	Linea aspera of femur, popliteal ligament	Calcaneus	Accessory to the gastrocnemius.
	Deep	Popliteus	Lateral condyle of femur	Posterior surface of body of tibia	Assists in flexing leg upon thigh, rotates tibia outward.
		Flexor hallucis longus	Posterior surface of body of tibia	Base of last phalanx of great toe	Flex the phalanges and extend the foot.
		Flexor digitorum longus	Posterior surface of body of tibia	By four tendons into last phalanges of four outer toes	
		Tibialis posterior	Aponeurotic septum between tibia and fibula	Under surface of navicular bone, calcaneus, three cuneiforms, the cuboid, second, third, and fourth metatarsals	Extends the foot at the ankle joint.
Lateral Muscles of Leg		Peroneus longus	Head and lateral surface of body of fibula	Lateral side of first metatarsal and first cuneiform	Extends and everts the foot, helps to maintain transverse arch.
		Peroneus brevis	Lateral surface of body of fibula	Fifth metatarsal bone	Extends the foot.

CHAPTER VIII

THE NERVOUS SYSTEM: DIVISIONS, NERVE TISSUE, THE REFLEX ACT

If the human body is compared to a coöperative community made up of industrial units, each one especially concerned with its own task, yet dependent upon the well-being and successful work of all the other units, it is obvious that some means of communication is essential. In our modern cities the telephone meets this need. In the human body the nervous system meets a similar need, and many others, for it controls human thought and conduct; gives us the power to perceive and appreciate the world about us; to see, to move, to hear, and to talk. It is the main factor in the control of the internal organs; and in addition, is constantly furnishing the body knowledge of its environment, interpreting this knowledge and adjusting the body to it. This knowledge (stimuli) is received

Fig. 103. — Diagram Illustrating the Brain, Spinal Cord, and Spinal Nerves.

by sense organs (end-organs of nerve fibers), conducted along sensory nerve fibers to the appropriate centers, and relayed from the centers by means of motor nerve fibers to the muscles or groups of muscles concerned. Some telephone calls have to be relayed through a number of exchanges, to the main exchange, *i.e.*, the very center of the system, other calls can be transferred in a local or subsidiary exchange without going to the main exchange. Just so in the human body, to meet some needs stimuli are relayed through many nerve centers to the main centers (brain), while other needs can be cared for in local or subsidiary centers, even without any knowledge on the part of the main centers. In other words, some of our adjustments are conscious and require the coöperation of the highest centers we possess, *i.e.*, the brain. Other adjustments, very important to our well-being, such as the motion of the stomach and intestines, are made unconsciously, or are cared for in subsidiary centers (*i.e.*, autonomic ganglia).

Just as the telephone system has a definite plan of exchanges connected by wires which ramify to all parts of the city, so we find the nervous system has a definite plan of centers (masses of nerve tissue) connected by nerve fibers which ramify to all parts of the body. The different parts of the nervous system may be classified in many ways. The following general classification[1] is suggested.

Nervous System
- **Central Nervous System**
  - Brain
  - Spinal cord
- **Connections** of centers in the Central Nervous System with the body-wall by cranial and spinal nerve fibers. *The Somatic or Craniospinal System.*
- **Connections** of centers in the Central Nervous System with the viscera by *autonomic fibers.*
  1. Nerve fibers from the brain and sacral spinal cord and ganglia (autonomic). *The Craniosacral or Parasympathetic System.*
  2. Nerve fibers from the thoracolumbar region of the spinal cord and ganglia (autonomic). *The Thoracolumbar or Sympathetic System.*

The craniospinal system. — This is also known as the cerebrospinal or voluntary nervous system. It includes: (1) those parts of the brain that are concerned with consciousness and all mental activities, (2) the parts of the brain, cord, and their nerve fibers

[1] An additional classification will be found in the summary.

that control the skeletal muscles, and (3) the end-organs of the body-wall.

The autonomic system. — This term means self-acting and includes all those parts of the nervous system which innervate: (1) all plain muscular tissue in the body, (2) the heart, and (3) the glands. As plain muscular tissue enters into the structure of all the viscera, this division of the nervous system is sometimes called splanchnic or visceral. It is also called involuntary because it is not under the control of the will, but it must not be thought of as an independent system, but as a closely correlated division of the whole nervous mechanism.

Nerve tissue. — This tissue enters into all parts of the nervous system. Like all other tissues it is composed of cells, but the cells are differentiated from other cells in that the protoplasm is extended, often to a distance of two or three feet, to form threadlike processes. These cells are called neurons. Each neuron is an anatomical and physiological unit.

Neuroglia. — This tissue consists of cells, called glia cells, which give off numerous processes that extend in every direction and intertwine among the neurons, forming a supporting framework. It is found only in the brain and spinal cord. In function neuroglia is a connective tissue, but it is derived from the ectoderm.

Properties of nerve tissue. — Nerve tissue possesses marked characteristics: (1) irritability (excitability), or the power to respond to stimulation, and (2) conductivity, or the power to transmit the stimuli or nerve impulses to other cells. The irritability of the neurons is of different sorts, in order to meet functional requirements; each sense organ is irritable only to its own special stimulus.

NEURONS

Nerve cells are called neurons (neurones). Each neuron develops from a single embryonic cell called a neuroblast. They vary greatly in size, shape, manner of branching, and number of processes, but consist of a cell-body and processes. These two parts make a complete nerve cell, which may be regarded as an elongated conductor. The nervous system consists of an enormous number of neurons. Connective tissue forms protective membranes covering different parts of the system, and in addition blood-vessels and lymph-channels are provided for nutritive and respiratory purposes.

The cyton or cell-body.[2] — The body of a nerve cell consists of a mass of granular cytoplasm surrounding a nucleus, which contains a well-defined nucleolus. Running through the cytoplasm and processes is an arrangement of fine fibrils called neurofibrils. They form a reticulum in the cell-body, are present in the dendrons, and the axons are composed almost entirely of them. Scattered throughout the cell-body and in the protoplasm of the larger dendrons are granular bodies which stain deeply with basic dyes, such as methylene blue. These are called Nissl's[3] granules, or chromophilic bodies, and are supposed to represent a store of nervous energy. The quantity is variable, depending upon the fatigue of the cell, rested cells showing a relatively greater amount.[4] The loss of chromophilic substance is called chromatolysis. It occurs in fatigue, certain fevers, asphyxia, and injury to the axon.

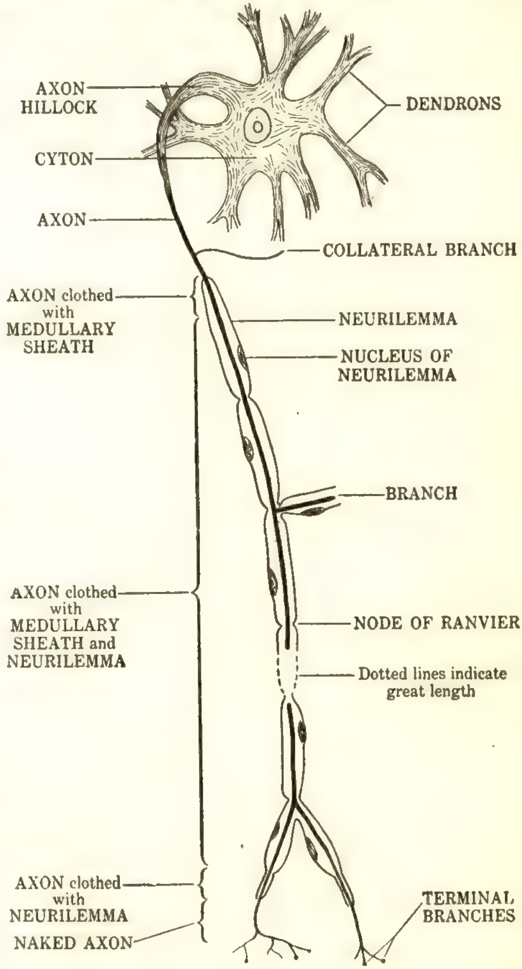


FIG. 104. — A MOTOR NEURON FROM ANTERIOR COLUMN OF SPINAL CORD.

The cell processes. — From the cell-body processes are given off. These processes are named dendrons and axons.

[2] Also called perikaryon.

[3] Franz Nissl, German neurologist, 1860–1910. Nissl granules are called chromophilic (color loving) because they take stains readily, especially methylene blue.

[4] In various mental diseases Nissl's granules are deficient or absent.

(1) *Dendrons or dendrites* are usually short and rather thick at their point of origin. They have a rough outline, diminish in caliber as they extend farther from the cell-body, and branch in a tree-like manner. The number of dendrons varies.

Axons or axis cylinder processes, also called neuraxons. — These processes differ from the dendrons in the following particulars: (1) They may be longer; in some instances their length may equal half a man's stature. (2) They have a smooth outline and diminish in caliber very little. (3) They give off one or more minute side branches called *collaterals.* (4) Usually each neuron has only one axon.

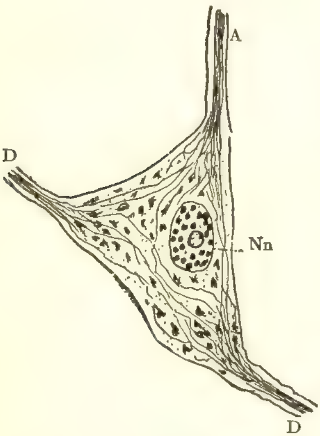


FIG. 105. — CELL-BODY OR CYTON. *A*, axon, *D*, *D*, dendrons, *Nn*, nucleus with contained nucleolus. The lines represent fibrils in the protoplasm of the cell, the dark spots represent Nissl or chromophilic granules. Note the absence of Nissl granules at the base of the axon. This area is known as the axon hillock. (Opitz.)

Function of the cell-body. — The cell-body is the source of energy and affords nutriment to its processes, as is proved by the fact that if a nerve fiber is cut, the part separated from the cell-body dies.

Function of the processes. — The essential function of the processes is conduction of nerve impulses either to the cell-body or from the cell-body. Processes which carry impulses *to* the cell-body are called dendrons, and those which carry impulses *from* the cell-body are called axons.

Function of the neuron. — Its function is to receive the nerve impulse and convey it to other cells. The structure is such that normally it can conduct in only one direction. Consequently each neuron possesses a distinct polarity, and the general arrangement of each neuron depends in a large measure upon the connections which it must establish with other neurons for functional purposes.

Classification of neurons. — Neurons are classified in many ways. One classification is based on the number of processes they possess.

(1) *Bipolar* cells are somewhat oval in shape, and from the two poles nerve processes are given off. They are found in the vestibular and cochlear ganglia of the ear. In the ganglia of the dorsal roots of the spinal nerves, so-called unipolar cells give off a single

T-shaped process, which rapidly divides. During the early stages of development they are bipolar cells, which gradually developed into the unipolar cell, as shown in *B*, Fig. 106.

(2) *Multipolar* cells possess numerous processes, which correspond to the number of angles or poles possessed by the cell body. It is in this group that the difference between axons and dendrons

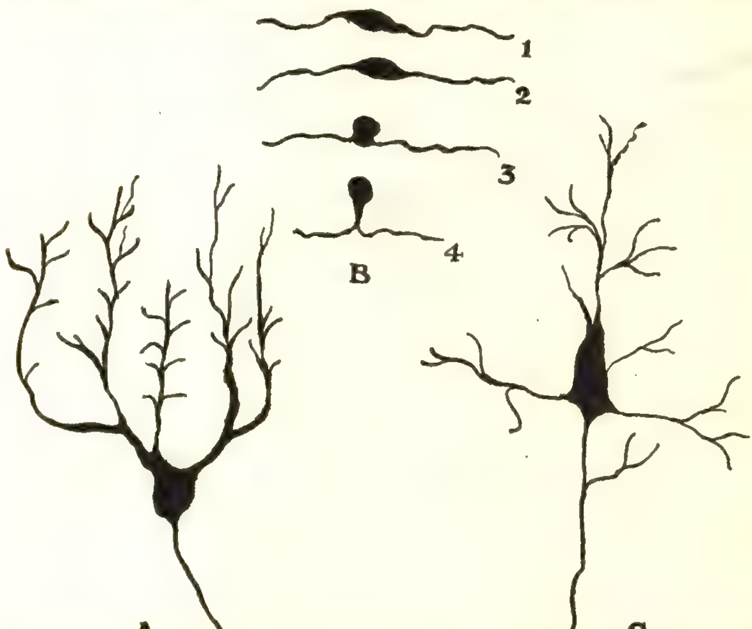


FIG. 106. — DIFFERENT TYPES OF NEURONS. *A*, cell of Purkinje from the cerebellum. *B*, pear-shaped cells from spinal ganglia on dorsal root of spinal nerve. 1 is a bipolar cell, 2, 3, and 4 show how it gradually develops into the unipolar pear-shaped cell of the ganglion. *C*, pyramidal cell from cerebral cortex.

is recognized. This group includes, in addition to the motor cells of the spinal cord, such cells as:

(*a*) the multipolar nerve cells of the anterior column of the spinal cord,

(*b*) the pyramidal-shaped cells of the cerebral cortex, which give off branching dendrons from each of the angles and one axon from the middle of the base, see *C*, Fig. 106,

(*c*) the flask-shaped cells of Purkinje,[5] found in the cortex of the cerebellum, which give off a single axon from their base, and from the apex, dendrons, which branch abundantly. See *A*, Fig. 106.

[5] Johannes Evangelistica Purkinje, Bohemian anatomist and physiologist, 1787–1869.

Golgi has divided nerve cells into groups, depending upon the length of their axons.

(1) The radical or root cells possess short dendrons and a single long axon.

(2) Short or association cells in which the axon branches rapidly are sometimes called Golgi cells. They are found in the gray matter of the brain and cord. (See Fig. 109.)

Another classification is based on the function they perform.

(1) Neurons which carry impulses from the periphery to the center are described as *afferent, receptor,* or *sensory.* The cell-bodies of this type of neurons are at some distance from their terminals. (See *R*, Fig. 109.)

(2) Neurons which carry impulses from the center to the periphery are described as *efferent, effector,* and *motor,* if they produce motion, or *secretory* if they produce secretion. The cell-bodies of this type of neuron are placed at one end. (See *E*, Fig. 109.) The effect of the impulse carried may be to excite activity or to lessen it. The former are called *excitatory,* and the latter *inhibitory.*

(3) Certain neurons carry impulses from the afferent neurons to the efferent neurons, and are designated as *central, connecting,* or *internuncial.*

Nerve fiber. — Nerve fibers do not exist independent of nerve cells, but are always outgrowths of these cells. These fibers as they extend away from the cell may become surrounded with sheaths and are of two kinds: medullated, or white fibers; and non-medullated, or gray fibers. Nerve fibers which conduct nerve impulses toward a center are called *afferent.* Those which conduct away from a center are called *efferent* with reference to that center.

Medullated fiber. — If one looks at a medullated nerve fiber under the microscope, it is found to consist of three parts:

(1) A central core, which is the fiber. (2) Immediately surrounding the fiber is a sheath, or covering, of a semi-fluid, fatty substance called the *medulla* or *myelin sheath.* It is to this fatty substance that medullated nerve fibers owe their white color. (3) External to the myelin sheath is a thin membrane completely enveloping the nerve fiber and forming the outer covering called the *neurilemma.* Medullated nerve fibers may be very long, but the diameter is minute.

Function of the myelin sheath. — It is thought that the myelin sheath insulates the nerve fiber and prevents the overflow and loss of the nerve impulse. There is some evidence that it plays

an important part in the chemical processes involved in the production of nerve impulses.

Nodes of Ranvier. — At regular intervals along the course of a medullated nerve fiber, the myelin sheath is interrupted and the neurilemma is brought close to the axon. These constrictions are the *nodes of Ranvier.*[6] It is thought that the purpose of the nodes is to allow tissue fluid to get to the fiber for nutritive purposes. In each internodal segment the neurilemma is seen to have a nucleus. These nuclei play an important part in the degeneration and regeneration of nerve fibers which are cut off from their cell bodies.

Medullated fibers found within the brain and spinal cord differ from those of the peripheral nerves. The myelin sheath is not segmented, and the neurilemma and nuclei are lacking.

Non-medullated fiber. — Non-medullated nerve fibers (*fibers of Remak* [7]) do not differ in any respect from the medullated nerve fibers save in the great reduction or absence of the myelin sheath, the fiber being directly invested by the neurilemma. Owing to the absence of the myelin sheath, the non-medullated fibers do not appear white, but present a gray or yellow color.

Synapse. — The majority of neurologists teach that each neuron is a separate and distinct unit. The fine branches of the axon of one neuron seem to interlace or dovetail with the dendrons of another neuron, forming a synapse. At the synapse the two neurons involved approach contact, and the nerve impulse passes from one to the other across a microscopic gap. In some cases a membranous barrier is interposed between the two neurons. The nature of this barrier is unknown, but it is probably not inert.

The conduction of the nerve impulse across the synapse differs from the conduction along a nerve trunk. The chief differences are:

(1) Conduction at the synapse is slower than conduction along a nerve fiber. This suggests that there is some sort of obstruction at the synapse.

(2) There is greater variability in the ease of transmission.

(3) Summation and inhibition seem to be brought about at the synapses.

(4) The refractory period is more highly variable.

(5) The synapses are more readily fatigued than the nerve fibers and are more readily affected by anæsthetics and such substances as nicotine.

[6] Louis Antoine Ranvier, French histologist, 1835–1922.

[7] Robert Remak, German anatomist, 1815–1865.

(6) In regions containing many synapses the blood supply is very rich, which suggests more active metabolism.

(7) A nerve fiber is capable of transmitting an impulse either to or from the cell-body, but at the synapse the nerve impulse can pass in only one direction, which is from the axon of one neuron to the dendron of another. In this way a synapse appears to function as a factor in establishing the polarity of neurons.

Formation of nerves. — A nerve fiber consists of a process with its coverings. A bundle of these fibers enclosed in a tubular sheath is called a *funiculus.* A nerve may consist of a single

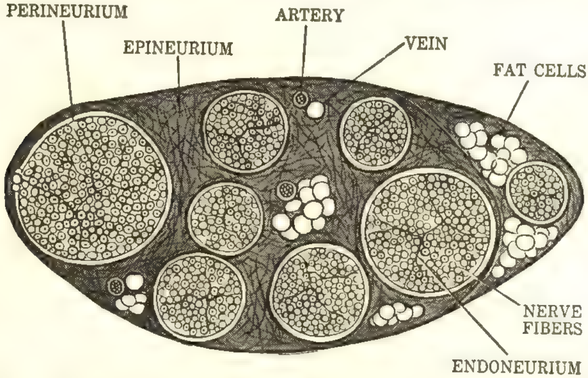


FIG. 107. — TRANSVERSE SECTION OF THE SCIATIC NERVE OF A CAT ABOUT × 100. This nerve consists of eight bundles (funiculi) of nerve fibers. Each bundle has its own wrappings (perineurium) and all the bundles are embedded in connective tissue (epineurium) in which arteries, veins, and fat cells can be seen.

funiculus or of many funiculi collected into larger bundles. Between the individual fibers is a small amount of connective tissue called *endoneurium* which serves to bind the fibers together into funiculi. Connective tissue called *perineurium* surrounds each funiculus in the form of a tubular sheath and all the funiculi are held in a connective tissue covering called the *epineurium.* The capillaries of the blood-vessels supplying a nerve penetrate the perineurium and either run parallel with the fibers or form short transverse connecting vessels. Fine nerve fibers (vasomotor) accompany these capillaries.

The nerves branch frequently throughout their course, and these branches often meet and fuse with one another, or with the branches of other nerves, yet each fiber always remains distinct. The nerve is thus merely an association of individual fibers which have very different activities and which function independently of one another. Most nerves are mixed nerves containing both afferent and

efferent fibers. Perhaps the best idea of the arrangement of nerves in a trunk can be obtained from a cross section of a nerve such as is seen in Fig. 107.

End-organs. — An end-organ is the peripheral apparatus related to a nerve. End-organs are of different types and may be classified according to their functions as sensory or receptor and motor or effector.

The sensory or receptor end-organs may be grouped as (1) exteroceptors, such as the retina, organ of Corti, tactile corpuscles, Pacinian corpuscles, sensory epithelium of the nose, taste buds, and sensory nerve terminations in the skin, such as end-organs for sensibility to heat, to cold, to pain, etc.; (2) proprioceptors, such as the end-organs on the surfaces of muscles, tendons, joints, organs for equilibrium sensations, etc.; (3) visceral receptors, such as taste-buds and those giving rise to sensations of hunger, thirst, nausea, respiratory sensations, circulatory sensations, etc.

The motor or effector end-organs are (1) the motor end plates associated with skeletal muscles, (2) end-organs associated with the visceral muscles, and (3) end-organs associated with glands.

Sensory receptors terminate in three ways. (1) The nerve fibers pass to the surface either in the skin or mucous membrane,

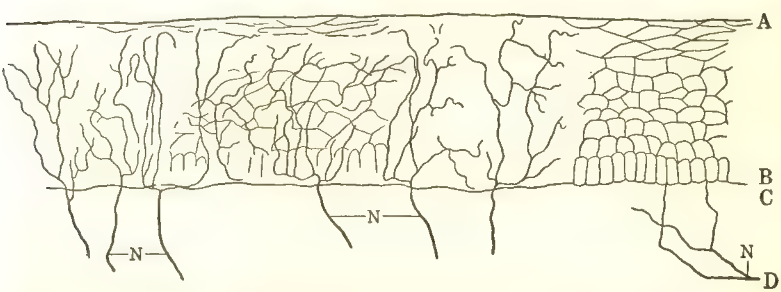


Fig. 108. — Sensory Nerve Terminations in Stratified Squamous Epithelium. *A* to *B*, epithelium; *C* to *D*, subcutaneous tissue; *N*, nerve fiber.

the neurilemma and myelin sheath disappear, the naked fiber subdivides into minute *arborizations* that ramify between the epithelial cells of the surface of the body. This method is the one in which sensory nerves terminate in the skin and its hairs and glands.

(2) Some of the highly complex special sensations need special end-organs for their reception. These are called *organules*. The *taste-buds* in the tongue, the *organ of Corti* in the internal ear, and the *rods* and *cones* in the retina are examples of organules.

(3) Nerve fibers approach the groups of muscle cells, tendons, and joints, and then subdivide into minute arborizations, which are wound around the muscle cells or spread out over the tendons or joints. They are known as end-organs for muscle, tendon, and joint sensibility.

Motor effectors are of two kinds. (1) Motor fibers intended to stimulate a skeletal muscle to activity terminate by a subdivision of the fibers (the neurilemma and myelin sheath fading out), each branch of the fiber ending in a flat nodule of granular material lying on the muscle cell. This terminal mass is the *motor end plate.*

(2) Motor fibers ending in involuntary muscles (such as in the viscera) terminate in a *plexus* or network of fibers. Motor fibers ending in glands terminate in a plexus of fibers.

Nucleus. — A collection of cytons within the central nervous system, the fibers of which go to form one anatomical nerve or a tract within the brain or cord, is called a nucleus, *e.g.*, the facial nucleus or nucleus of the facial nerve.

Ganglion. — A collection of cytons outside the central nervous system is called a ganglion. Ganglia appear in the course of the cranial and spinal nerves and form the ganglia of the autonomic system.

Center. — A group of neurons and synapses regulating a certain function is called a *nerve center.* It may be either a nucleus or a ganglion, as these two terms refer to an anatomical entity, and the term center refers to a functional entity. For instance, the rate of respiration is controlled by a center in the medulla oblongata, and odor is interpreted by a center in the cerebrum. In order to control an organ the center must be in communication with the organ by means of nerve fibers and end-organs adapted to receive and transmit impulses. Usually the fibers which connect the centers with the organs they control do not extend all the way, but terminate in masses of gray matter which serve as relay stations where they form synapses with other neurons that carry their impulses onward, possibly to one or more relay stations, or directly to the organ. There may be one or several relay stations. In any such series, the neuron first to be stimulated is called the neuron of the first order, and the succeeding neurons are called neurons of the second, third, and fourth order, etc.

Gray and white matter. — The cell-bodies of neurons and many of their processes are grouped together into what we call gray matter. Gray matter is found in the cortex of the brain, the core

of the spinal cord, making up the nuclei and ganglia, and unmyelinated nerve fibers.

The medullated processes of cell-bodies are grouped together, as described, into nerves, and these nerves constitute what we call white matter. It will therefore be seen that the gray matter contains the cell-bodies and the synapses where the adjusting of sensory to motor neurons takes place, and the white matter is made up of the conductors of nerve impulses, chiefly myelinated conductors.

THE REFLEX ACT

In the same way that the *nervous system* may be reduced to a simple unit designated as the neuron, so *nervous action* may be

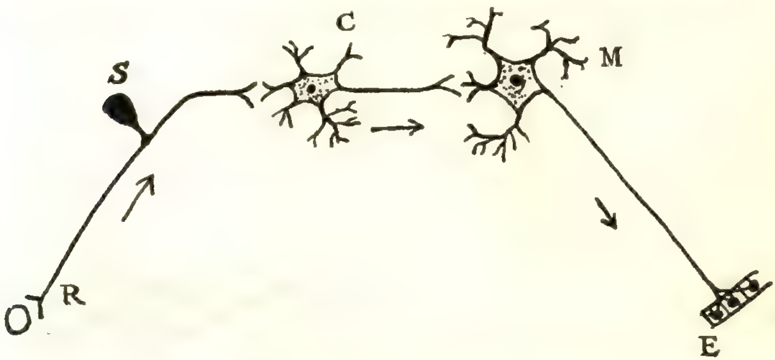


FIG. 109. — A REFLEX CIRCUIT CONSISTING OF A SENSORY, CENTRAL, AND MOTOR NEURON. *S*, sensory cell; *C*, central cell; *M*, motor cell; *R*, receptor; *E*, effector mechanism.

reduced to the so-called reflex act, which means a response to a sensory stimulus. Just as the neuron forms the building stone of the nervous system, so the reflex act forms the functional basis of nervous activity. At least two neurons enter into the formation of a reflex circuit (arc), a receptor or sensory neuron and an effector or motor neuron.

A receptor or sensory neuron is one in which the afferent process ends in a receptor of one kind or another. An effector or motor neuron is one in which the efferent process ends in a muscle or gland cell. Neurons which are interposed between other neurons are called central, connecting, or internuncial neurons.

A simple reflex circuit may consist of a sensory and a motor neuron. It is doubtful if there are any two cell reflexes in the adult vertebrate body. Most reflex circuits consist of a sensory neuron,

one or more central neurons, and a motor neuron, or of complexes of each of these.

Fig. 109 illustrates a reflex circuit consisting of a sensory, central, and motor neuron.

On applying an appropriate stimulus to the receptor ending of the sensory neuron, an impulse is generated which passes along the dendron to the cyton, thence along its axon, across the synapse, through the central neuron and across another synapse to a dendron of the motor neuron, then through its cell-body and axon to the muscle or gland cell where action is produced.

Because of its likeness to a telephone system the peripheral end of the sensory nerve is called the receptor (telephone transmitter). The processes are called conductors (telephone wires), the synapses, and cell-bodies are called adjusters (telephone operators), and the ending in muscle or gland cell an effector (telephone receiver). The receptor receives the stimulus, transforms it to a nerve impulse, and passes it on to the dendron. In the adjusting mechanism the nerve impulse may be transferred across some synapses rather than others, for it must be remembered that each neuron forms synapses not simply with one neuron, as in Fig. 109, but often with many, as in Fig. 110. The effector mechanism receives the nerve impulse, transforms it to a stimulus, and passes it on to a muscle or gland cell. Between the simplest form of involuntary activity and the higher activities that involve consciousness, memory, or control, are many types of reactions. These are usually grouped in three levels:

(1) *Reactions of the first level* or simple reflexes depend upon a sensory neuron, a central neuron, and a motor neuron. Stimulation of the sensory neuron may result in response by a muscle. Examples of such simple reflexes are the winking reflex caused by an object striking or appearing as if it would strike the cornea, the swallowing reaction due to food on the back of the tongue, avoiding reactions due to tickling, pricking, the application of heat or cold, etc.

First level responses are of value in diagnosis of diseases of the nervous system, because in general they are simple, direct, the response is rapid, they can be predicted with relative safety, persist throughout life, and can be modified or inhibited only with difficulty.

(2) *Reactions of the second level* involve neurons extending up into the brain stem and cerebellum. In Fig. 110 the reaction starting with a sense organ, extending to the midbrain and then to the

muscles, illustrates a connection on the second level. Reactions on this level are more complex, not so rigid, more readily modified and varied and, as a rule, involve greater regions of the body. Many of the muscular coördinations concerned with walking, running, etc., are examples of second level reactions.

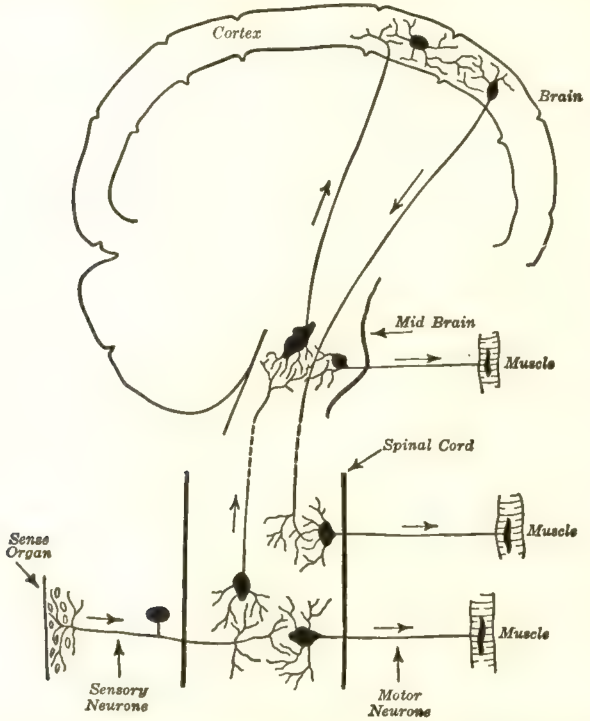


FIG. 110. — CONNECTIONS OF THE FIRST, SECOND, AND THIRD LEVELS. The arrows indicate the direction of the nerve impulses. The area between the two lines at the top of the brain represents the cortex. (Gates.)

(3) *Reactions of the third level* involve neurons in the cerebral cortex, as illustrated in Fig. 110. In the cerebral cortex the possibilities of a wide range of connections between the receptor and effector mechanisms of the body are almost limitless. The reactions often involve many widely different regions of the body. The simple withdrawal of a finger from a prick is an example of a first level reflex. If at the same time one cries out, there is an example of the second level. If in addition one deliberately dresses the wound, there is an example of a third level reaction.

Classification of reflexes. — Reflex circuits may be classified according to the response brought about by a stimulus, as:

(1) Simple[8] reflexes or those in which a single muscle is affected, *e.g.*, the winking reflex in which only the orbicularis palpebrarum is concerned.

(2) Coördinated or complex reflexes, or those in which several muscles are concerned, the reaction remaining perfectly coördinated.

(3) Convulsive reflexes, such as are seen in spasms, in which there is no coördination of muscular activity, the resulting movements being disorderly.

Nature of a nerve impulse. — The nature of a nerve impulse is not known. We know that nerve fibers may be stimulated artificially by several means, and the practical result is similar to the result obtained when the nerve is stimulated by the natural physiological impulse. The nerve fiber has no power to initiate a nerve impulse, but serves merely as a conductor of the impulse.

There are four means usually applied to the artificial stimulation of a nerve fiber, *viz.:* chemical, thermal, mechanical, and electrical. The latter is the most usual. That the true physiological impulse is none of these can readily be proved. However, both electrical and chemical changes are associated with the conduction of nerve impulses, and the generally accepted theory is that a nerve impulse is a form of energy of a physico-chemical nature, and the physical phenomena are of an electrical nature, though not identical with an electrical current.

Identity of nerve impulses. — Nerve impulses are considered to be identical in character and vary only in intensity; that is, the rate at which they travel along the nerve fiber. According to this belief the impulses carried by a sensory nerve, such as the optic, are similar to those carried by a motor nerve. In one instance we get a visual sensation and in the other contraction of a muscle. The difference in result is due to the optic nerve ending in the visual center in the cerebrum and the motor nerve ending in a muscle. In this connection physiologists use the expression *specific nerve energy* to express the fact that, when stimulated, nerve fibers give only one kind of reaction regardless of what the stimulus may be. Normally impulses start at the receiving end-organs of a nerve

[8] Neurologists have developed special tests for such reflexes as the wink, pupillary and patellar reflex. Patellar reflex is the name given to the jerk of the foot caused by tapping upon the patellar ligament while the leg is crossed, or suspended across the edge of a table or chair. The impulses generated are conveyed to the sciatic center and thence to the quadriceps femoris muscle, which contracts and extends the leg. The varying intensity of this reflex is indicative of the irritability of the entire nervous system. Injuries to the cord may abolish this reflex entirely. Lesions of the higher centers increase its intensity.

fiber, but they can be induced at any part of the nerve fiber. When this happens the brain projects the resulting sensation to the part containing the receptors of the fibers stimulated. This explains why patients who have suffered an amputation refer the pain in the stump to the part that has been removed. The pressure of the surgical dressings or new tissue on the nerve fibers is comparable to tapping a telegraph wire between stations, and the message received is interpreted as coming from the station, which in the body is the receptor.

Reaction of receptors and nerve centers. — Each type of receptor is sensitive to only one kind of stimulus. If an unusual stimulus is applied, the sensation aroused is similar to the sensation resulting from the usual stimulus. For instance, the usual stimulus of the receptors of the optic nerve (in the retina of the eye) is light waves, but an unusual stimulus, such as pressure on the eyes, gives rise to a sensation of light. This is equally true of the nerve centers. If they are stimulated in an unusual way, they interpret the stimulus as being of the usual kind, which is the reason why a blow on the head, or a fall that jars the spinal cord, is likely to stimulate the sight center, and flashes of light are seen.

Reaction time. — This term is applied to the time elapsing between the application of a stimulus and the beginning of a response. Reaction time varies in different individuals and in the same individual under different conditions, depending upon: (1) the strength of the stimulus, the stronger the stimulus the more prompt the response; (2) the nature of the stimulus, for example, the response to sound is more prompt than that to light; and (3) the number of synapses through which impulses are transmitted determines to some extent the length of time required for responses.

Some authorities state that the time required for conduction within the nerve centers may be twelve times as great as that required for conduction along the sensory and motor nerves. The time within the center varies, depending upon (1) the strength of the stimulus, (2) the condition of the nerve centers, the time being lengthened by any condition, such as fatigue that lessens the irritability of the center.

The *speed* at which a nerve impulse travels along a nerve fiber varies in different varieties of fibers, but is estimated to be about 120 meters (395 ft.) per second in a medullated nerve fiber in man. In general, the speed of the nerve impulse varies with the diameter of the fiber. The velocity of the nerve impulse over any nerve refers to the velocity over the largest fibers.

Chronaxie is the measure of the excitability of a tissue. The

chronaxie of tissue is the shortest duration of time over which an electrical current of twice the rheobasic strength must be applied to stimulate the tissue.

There seems to be a close relationship between the chronaxie and the diameter of nerve fibers. The finer fibers are less excitable, *i.e.*, have a longer chronaxie than the large ones.

Summation of stimuli. — Stimuli which are so slight that they fail to produce a response are described as subminimal. A succession of subminimal stimuli will produce a response, due to the fact that each successive stimulus renders the nerve cell more sensitive. This is known as the summation of stimuli. It is thought that the power of summation is a characteristic property of the nerve cell, and is the property which enables nerve centers to respond to a series of stimuli or to continuous stimulation. Excessive stimulation of neurons will cause changes which interfere with their functioning, and excessive stimulation of nerve centers will result in their depression.

For a brief period (.002 to .003 second) after stimulation a nerve fiber exhibits a *refractory period*, during which it is not irritable to a second stimulus.

Diffusion of impulses. — All parts of the nervous system are bound together by connecting pathways. Some of these pathways are long, well-defined bundles of fibers connected in a way to facilitate uniform and definite responses to stimulation. Other pathways are diffuse, poorly integrated, and not well adapted to conduct impulses for long distances. Incoming impulses have many pathways open to them. Usually the resistance offered at the synapses prevents their too wide diffusion, and the formation of pathways reënforces this limitation. However, a strong stimulus may produce a great diffusion of impulses through the gray matter, and in extreme cases efferent impulses may be sent to all the muscles, causing contractions and resulting in convulsions. In early life diffusion of impulses occurs much more readily than in later years, which accounts for the fact that conditions which cause marked muscular contractions or convulsions in a child often cause only mild contractions or a chill in adults. In some cases light stimuli may cause marked diffusion. It is thought that: (1) certain drugs (like strychnin and caffein) affect the synapses and render the passage of impulses easier; (2) some toxins produce a state of abnormal irritability or sensitiveness; and (3) there may be a summation of mild stimuli such as the irritation due to intestinal worms.

Convergence of impulses. — Nerve impulses from many receptors may pass to one effector mechanism. This is called convergence. Each muscle is connected with a number of receptors and it follows that the stimulation of two receptors will produce a more vigorous response than the stimulation of one, three will be more effective than two, etc. The energy of one impulse is added to the energy of other impulses activated at the same time, when all have more or less open pathways to a common effector.

Facilitation. — After establishment of a reflex, its repetition becomes increasingly easy and the reaction time lessens, within limits. This is known as facilitation and is the basis of habit formation.

Inhibition. — If every stimulation were followed by its full response, the body would be "on the jump" all the time. This overactivity is checked by the partial or complete blocking of impulses or their results, which is known as inhibition. In addition to blocking, inhibition brings about an actual depression of the activity of the effector, *e.g.*, reduces the tone of muscle. We do not know how this is brought about, but all effector mechanisms can be inhibited as well as stimulated. Diffusion and convergence of impulses, facilitation, and inhibition make a wide range and greater variety of reactions possible. Physiological conditions at the synapses are important in relation to the ease and direction of the traveling of the nerve impulses over these reflex mechanisms.

Reflexes whose adjusting mechanism is in the cord may be inhibited by centers in the cerebrum. Micturition is an example. Micturition is probably brought about as a spinal reflex, the stimulus starting from receptors in the bladder itself, so that when the bladder is filled, it automatically empties itself. Due to training in early infancy, this simple reflex may be inhibited from the cerebrum, so that micturition takes place only under voluntary control. The same is true of defecation. Such reflexes are called *educated* or *conditioned reflexes*. If in diseases of the nervous system the spinal reflexes remain intact, but the conducting paths to the cerebrum are interrupted, the spinal reflex may control, resulting in involuntary micturition and defecation.

Habit. — An impulse which is made to pass through a certain set of neurons and their synapses a great many times is thought gradually to break down the resistance in its path, and future impulses will pass through the same pathway more readily. This is true of all the activities of the nervous system. Repetition of an act renders its performance easier and leaves some change in the pathway involved. Such changes are the basis of habit formation, memory, and character.

Automatic action. — Some of the nerve centers are in a state of constant stimulation due (1) to some unknown inherent property, and (2) to substances contained in the circulating blood which are constantly acting upon them. In consequence they are constantly discharging impulses to the organs they innervate. The centers controlling respiration and the action of the heart are of this type and are described as automatic.

Fatigue of nerve cells. — Various authorities state that a normal neuron when stimulated first increases in size (due to increased metabolism), but long-continued activity decreases the size of the cell-bodies, reduces the granular material of the cytoplasm and the chromatic material of the nucleus. If the fatigue is not excessive, a period of rest will restore the cells to a normal condition. It is thought that fatigue of nerve cells may be brought about in two ways, namely, by causing an accumulation of waste products, or by exhausting the reserve nutritive material of the cell. The first is known as the fatigue of depression, and the second as the fatigue of excitation. Nerve fatigue is induced by both mental and muscular work. In the former case the fatigue substances are developed in the brain, in the latter case they are developed in the reflex centers maintaining muscular activity and in the muscles themselves; they are then absorbed by the blood and carried to all parts of the nervous system.

The onset of fatigue is favored by poor health and mental conflict of any kind, such as regrets, worry, fear, etc. Conscious effort to keep the attention concentrated induces fatigue more readily than when such effort is not necessary. Work done under compulsion, as from a sense of duty, results more readily in fatigue than when interest is the driving motive.

Constant irritation, such as eyestrain, abnormal conditions of the feet, prolonged distention of the intestine with feces such as occurs in chronic constipation, in fact anything that causes pain or a continued sense of discomfort, brings about conditions in the nervous system similar to those caused by fatigue.

One of the results of fatigue is to increase the resistance to the passage of impulses at the synapses, and the higher cerebral centers are most easily and quickly affected. It is for this reason that young children "go stale" very quickly unless their mental training is properly balanced by rest and play.

It is often stated that change of activity is equivalent to rest. It is questioned whether this is true of mental activity, but it may be true of muscular activity, and the explanation offered is that

when nervous stimuli are altered, new pathways and new groups of muscles are called into play. For example, a person who is tired of housework may go out of doors and walk, because the fresh air, changed environment, and different thoughts serve as new stimuli, travel different brain paths, and throw into activity different groups of muscles.

Normally the fatigue of nerve tissue resulting from each day's activities is repaired by a night's sleep, but if day after day, for an extended period, the fatigue is excessive, it accumulates, as it were, and a pathological condition results. This is more apt to happen if mental conflicts add their quota. If in addition monotony — which means the same neurons are activated by the same kind of stimuli each day — is added, abnormal states, variously known as brain fag, neurasthenia, and nervous prostration, are likely to develop. The depression of the higher cerebral centers is usually the starting point of such a condition. If the will power is weakened, the power of concentration lessened, and the higher mental capacities reduced, the imagination is likely to substitute morbid ideas and fears (phobias) that under ordinary circumstances would not be thought of, or if they were, would be rejected, or reasoned away.

Worry and fear stimulate parts of the autonomic system and bring about conditions in the alimentary canal that favor indigestion and constipation, two complaints that are associated with a wide range of neurasthenic conditions.

Hypersensitiveness, or excessive response to stimuli, often follows the depression of the higher inhibition capacities. Even slight stimuli may be interpreted as pain, and ordinary sounds are regarded as loud noises. It is while in this condition that an individual is susceptible to suggestion which may help him to regain his control, or on the other hand may be his undoing, for if he hears of abnormal symptoms, he is likely to think he has them, and he may acquire them, for it has been proved that the vascularity and sensitiveness of a part may be increased if the attention is centered upon it. It is to this state that the advertisements of patent medicines, which include long lists of symptoms that can be cured by the particular remedy advertised, make their appeal, and this group of sufferers are the ready victims of many kinds of quacks.

SUMMARY

- **Functions of Nervous System**
  - Serves as means of communication between different parts of the body.
  - Controls human thought and conduct.
  - Gives power to perceive and appreciate world about us, to see, to move, to hear, and to talk.
  - Main factor in control of internal organs.
  - Furnishes body knowledge of environment.
  - Interprets this knowledge and adjusts to it.

- **Adaptation of Langley's Classification**
  - 1. **Central nervous system**
    - Spinal cord.
    - 31 pairs of spinal nerves.
    - End-organs.
    - Brain
      - Cerebrum.
      - Mid-brain.
      - Cerebellum.
      - Pons Varoli.
      - Medulla oblongata.
    - 12 pairs cranial nerves and end-organs.
  - 2. **Autonomic nervous system**
    - Para-sympathetic
      - Ocular
        - Tectal autonomics.
      - Oro-anal
        - Bulbar autonomics.
        - Sacral autonomics.
    - Sympathetic
      1. Centers in the cervical, thoracic, and lumbar regions of the cord.
      2. Sympathetic ganglia and their fibers.
      3. The great plexuses.
    - Enteric
      - Plexuses in the walls of the alimentary canal.

- **Classification of Nervous System based on function**
  - **Receptors**
    - Somatic
      - Exteroceptors.
      - Proprioceptors.
    - Visceral
      - General.
      - Special.
  - **Conductors or Nerve Fibers**
    - Afferent (sensory, receptor).
    - Efferent (motor, effector).
  - **Adjustors (gray matter cells and synapses)**
    - Brain
      - Cortex
        - Cerebrum.
        - Cerebellum.
      - Centers or Nuclei
        - Cerebrum.
        - Cerebellum.
        - Medulla.
    - Cord
      - In interior.
    - Ganglia
      - Those on sensory roots of nerves, autonomic ganglia, and terminal ganglia.
  - **Effectors**
    - Skeletal muscles.
    - Visceral muscles.
    - Glands.

- **Function**
  - Somatic Nervous System, Cerebrospinal or Voluntary Nervous System includes
    1. Parts of the brain concerned with consciousness and mental activity.
    2. Parts of the brain, cord, and their nerves that control skeletal muscles.
    3. End-organs of all of special sense nerves.
  - Close correlation between these two divisions.
  - Autonomic System, Visceral, Splanchnic or Involuntary Nervous System includes
    - All those parts of the Nervous System which innervate
      1. All plain muscular tissue in body.
      2. The heart muscle.
      3. The glands.

Nerve tissue. — A tissue of differentiated cells called neurons.

Neuroglia. — Consists of cells that give off processes which form a supporting network for neurons in the brain and spinal cord. Derived from the ectoderm.

- **Properties of Nerve Tissue**
  1. Irritability, or the power to respond to stimulation.
  2. Conductivity, or the power to transmit stimuli.

- **Neuron Concept**
  - The nervous system may be reduced to a simple unit called a neuron which may be regarded as the building stone of the nervous system.

- **Neuron**
  - Cell body
    - Mass of cytoplasm containing fibrils and Nissl granules.
    - Cytoplasm surrounds nucleus which contains a nucleolus.
    - Function — source of energy and affords nutriment to its processes.
  - Cell processes
    - Dendrons or dendrites
      - Usually short, break up into many branches. Rough outline — diminish in caliber. May be one, or many.
    - Axons, neuraxons, or axis cylinder processes
      - May be long, smooth outline, diminishes in caliber very little. Gives off collaterals. Each neuron has one axon.
    - Function is conduction of nerve impulses either *to* the cell body (dendron) or *from* the cell body (axon)

- **Function of Neurons**
  - Receive nerve impulse and convey it to other cells.
  - Can conduct in only one direction, hence distinct polarity.
  - Afferent, receptor, sensory neurons
    - Carry impulses from periphery to center.
  - Central, connecting or interncuncial neurons
    - Carry impulses from sensory neurons to motor neurons.
  - Efferent, effector, motor neurons
    - Carry impulses from center to periphery.

- **Classification of Neurons**
  - According to number of processes
    - Bipolar.
    - Multipolar.
  - Depending on length of axons
    - Radical or root cells.
    - Short or association cells.

Classification of Neurons
- According to function
  - Afferent, receptor, sensory.
  - Central, connecting or internuncial.
  - Efferent, effector
    - motor.
    - secretory.

Nerve fiber
- Medullated
  - Fiber
  - Myelin sheath — function
    - Protects and insulates.
  - Neurilemma
- Non-medullated
  - Fiber.
  - Neurilemma.

Nodes of Ranvier
- Ring-like constrictions in medullated fibers, due to absence of myelin sheath.
- Minute side branches called collaterals given off from nodes.

Synapse
- Interlacing of the fine branches of the axon of one neuron, with the branches of a dendron of another neuron. *Not* an anatomical continuation. Nerve impulses are able to bridge the microscopic gap.

Nerves
- Bundles of nerve fibers bound together to make funiculi.
- Funiculi bound together to make nerve trunks.
- Connective tissue surrounds funiculi (perineurium) and nerve trunks (epineurium).

End-Organs
- **Function and location**
  - Peripheral apparatus related to a nerve.
  - Sensory or Receptors
    - Somatic
      - 1. Exteroceptors.
      - 2. Proprioceptors.
    - Visceral
      - General.
      - Special.
  - Motor or Effectors
    - Somatic effectors.
    - Visceral effectors.
- **Function and structure**
  - Sensory or Receptors
    - End arborizations.
    - Organules.
    - End-organs for muscle, tendon, and joint sensibility.
  - Motor or Effectors
    - Motor end-plate.
    - Plexus or network.

Nucleus. — A grouping of the cell bodies within the central nervous system the fibers of which form one anatomical nerve or tract within the brain or cord.

Ganglion. — A grouping of the cell bodies of several neurons outside the central nervous system.

Center. — A group of neurons regulating a certain function. May be either a nucleus or a ganglion.

Classification of Nerve Tissue
- **Gray Matter**
  - Cell bodies of neurons and many of their processes.
  - Found in
    - Cortex of brain.
    - Core of spinal cord.
    - Nuclei and ganglia.
- **White Matter**
  - Medullated processes of cell bodies grouped together into nerves.

Reflex Act
- Nervous action of all kinds may be reduced to the reflex act. The reflex circuit forms the functional basis of all nervous activity.

Types of Reflex Circuits
1. Consists of two neurons
   - Receptor or sensory.
   - Effector or motor.
2. Consists of three neurons
   - Receptor or sensory.
   - Central.
   - Effector or motor.
3. Consists of complexes of above.

Classification of Reflexes
- First level — cord.
- Second level — brain stem and cerebellum.
- Third level — cerebral cortex.
- Simple — single muscle involved.
- Coördinated or complex — several muscles involved in orderly activity.
- Convulsive or disorderly activity.

Nature of Nerve Impulses
- Not positively known.
- Thought to be of a physico-chemical nature.
- Identical in character, vary only in intensity.

Reaction of Receptors and Nerve Centers
- Not all affected by the same stimuli.
- Special end-organs to mediate each sense.

Reaction Time
- Time elapsing between application of stimulus and beginning of a response.
- Depends upon
  1. Strength of the stimulus.
  2. Nature of stimulus.
  3. Number of relay stations through which impulses are transmitted.
- 120 meters (395 feet) per second in medullated nerve fiber in man.

Summation of Stimuli
- Subminimal stimuli — too slight to produce response.
- Succession of subminimal stimuli renders nerve cell more sensitive — this is described as summation.

Diffusion of Impulses
- Incoming nerve impulses have many nerve paths open to them.
- Resistance offered at synapses and pathways limits diffusion.
- Very strong stimulus may overcome resistance — efferent impulses sent to all muscles, thus producing convulsions.
- Summation of stimuli may produce similar effect.

Convergence of Impulses
- Impulses from many receptors pass to one effector mechanism.
- Stimulation of two or more receptors produce a more vigorous response.

Facilitation
- Repetition lessens time of reflex.
- Basis of habit formation.

Inhibition
- Partial or complete blocking of impulses or their results.
- Actual depression of the activity of the effector.

Habit
- Term applied to lessened resistance in nerve pathway that is frequently used.

Automatic Action
- Some of the nerve centers are in state of constant stimulation.
- Due to
  - Some unknown inherent property.
  - Substances in the blood, which act upon them.

Fatigue of Nerve Cells

- When first stimulated neurons increase in size.
- Long-continued activity
  - Decreases size of cell bodies.
  - Reduces granular material of cytoplasm.
  - Reduces chromatin of nucleus.
- Varieties
  - Fatigue of depression — due to accumulation of waste products.
  - Fatigue of excitation — due to exhaustion of the nutritive material of cell.
- Due to
  - Mental and muscular work
    - Fatigue substances developed in brain, in reflex centers and muscles carried by blood to all parts of the nervous system.
    - Poor health, mental conflicts, efforts at concentration, favor onset.
- Result — Resistance at synapses increased.

CHAPTER IX

THE SPINAL CORD AND SPINAL NERVES; BRAIN AND CRANIAL NERVES; AUTONOMIC SYSTEM

A brief sketch of the lower animals, characterized as segmental, is helpful in understanding the structure and functions of the spinal cord. Segmental animals are made up of a number of smaller units which may be capable of leading an independent existence. This is made possible by the fact that each segment possesses separate circulatory, digestive, excretory, and nervous systems, so that the segments may be separated without endangering or seriously impairing their life processes. As far as the nervous system is concerned, we find that each segment of these animals is equipped with a centrally-placed ganglion from which nerve fibers extend in all directions to the different tissues of the segment. A stimulus applied to its surface is soon followed by movement or some other motor response. It appears, therefore, that the nervous elements allotted to each segment are arranged in the form of reflex circuits, their centers being grouped in the shape of a central ganglion. The life of the animal as a whole, however, requires a certain *correlation* between the activities of its different segments and a *subordination* of the latter to the functional necessities of the whole. This end is attained first by intermediary neurons which unite the successive ganglia with one another, and secondly, by a hyperdevelopment of the head-ganglion which thus gains a directing control over the others.

A nervous system of this kind is reflex in its nature and forms the basal stem around which the nervous system as it appears in the highest animals is eventually developed. The head-ganglion is comparable to the brain, the segmental ganglia to the spinal cord, and from these parts the afferent and efferent nerve fibers arise.

THE SPINAL CORD

The spinal cord is that portion of the nervous system lodged within the spinal canal of the vertebral column. It consists of a collection of gray and white substance, extending from the foramen magnum of the skull, where it is continuous with the medulla

oblongata, to about the second lumbar vertebra, where it tapers off into a fine thread called the *filum terminale.* Before its termination it gives off a number of nerves which form a tail-like expansion, called the *cauda equina.* It diminishes slightly in size from above downward, with the exception of presenting two enlargements in the cervical and lumbar regions, where the nerves are given off to the arms and legs respectively. Its average length is about 45 cm. (18 in.). The spinal cord is incompletely divided into lateral halves by a ventral fissure and a dorsal sulcus; the ventral fissure dividing it in the middle line in front, and the dorsal sulcus in the middle line behind. Because of these fissures, only a narrow bridge of the substance of the cord connects its two halves. This bridge, called the transverse commissure, is traversed throughout its entire length by a minute *central canal,* which opens into the fourth ventricle at its upper end and at its lower terminates blindly in the filum terminale.

Meninges or membranes. — The spinal cord does not fit as closely into the spinal canal as the brain does in the cranial cavity, but is suspended within it. It is protected and nourished by three membranes which are continuous with the membranes covering the brain and are called by the same names, *viz.:* the pia mater closely investing the cord, the arachnoid, and the dura mater outside.

Structure of the cord. — The cord consists of gray and white matter, the former being enclosed within the latter. The gray matter consists of nerve cells and nerve fibers held together by neuroglia. The white matter consists of nerve fibers embedded in a network of neuroglia. The gray and white matter are supported by connective tissue, and are well supplied with blood and lymph-vessels.

The *gray matter* is in the interior surrounding the central canal and on cross section appears to be arranged in the form of the letter H. The transverse bar of the H is called the gray commissure, and connects the two lateral masses of gray matter. On each side the gray matter presents a ventral or anterior, and a dorsal or posterior column.[1] The former is short and bulky while the

[1] The terms used in describing the different portions of the spinal cord vary in different texts; for instance, Gray's *Anatomy* uses *anterior* and *posterior* for the front and back respectively; Herrick's *Introduction to Neurology* uses *ventral* and *dorsal.* In this text we are using *anterior* and *ventral* for the front aspect, *posterior* and *dorsal* for the back, and *columns* for what were formerly described as *horns* of the gray matter. For each of the three major divisions of the white matter of each half of the cord, we are using *funiculus* instead of *column.* Each funiculus is made up of bundles or fasciculi.

latter is long and slender. The ventral column contains the cell bodies from which the efferent (motor) fibers of the spinal nerves arise. These pass out through openings in the meninges and the intervertebral foramina. The lateral aspect of the ventral column contains cell bodies which give rise to the efferent fibers of the white *rami communicantes*[2] (see Fig. 123) or preganglionic fibers, which connect with the sympathetic ganglia outside the vertebral column. The dorsal column contains cell-bodies from which afferent, ascending fibers go up to the brain. The fibers of the

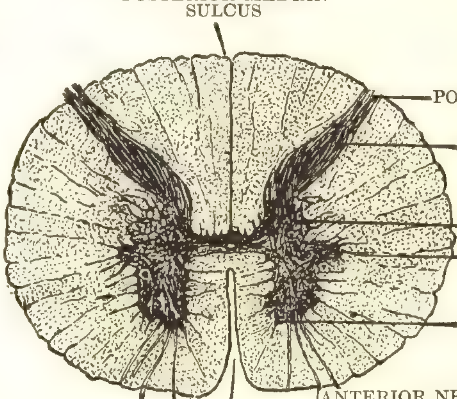


FIG. 111. — TRANSVERSE SECTION OF THE SPINAL CORD AT THE MIDDLE OF THE THORACIC REGION. (Gerrish.)

spinal nerves entering the cord form synapses with the neurons in these columns. The gray matter also contains a great number of central or connecting neurons which serve for the passage of impulses (1) from the dorsal to the ventral roots of the spinal nerves, (2) from one side of the cord to the other, (3) from one level of the cord to another.

The *white matter* is arranged around and between the columns of gray matter, the proportion of gray and white varying in different regions of the cord. On each side the white matter may be said to consist of three portions or funiculi, namely, a ventral, a lateral, and a dorsal funiculus. Each funiculus is in turn divided into smaller segments or fasciculi.

[2] Preganglionic fibers are efferent, medullated fibers (white rami) which pass from the spinal cord by way of the ventral column, and end by arborizing around the cells of an autonomic ganglion. From the cells of the ganglion, postganglionic fibers go to the various effector organs, *i.e.*, smooth muscle, cardiac muscle, and glands. The latter are non-medullated. Some pass back to the spinal nerves and form the gray rami. (See Fig. 121.)

Some of these funiculi consist of fasciculi made up of fibers which are ascending or sensory. They serve as pathways to the brain for impulses entering the cord over afferent fibers of spinal nerves. They begin in the dorsal root ganglia or in the gray matter of the cord, ascend, and terminate in the gray matter of the brain, *e.g.*, 1, 2, 4, 5, in Fig. 112. Other funiculi consist of fasciculi which are descending or motor. They transfer impulses from the brain to the motor neurons of the spinal nerves. They begin in the gray matter of the brain, descend, and terminate in the gray matter of

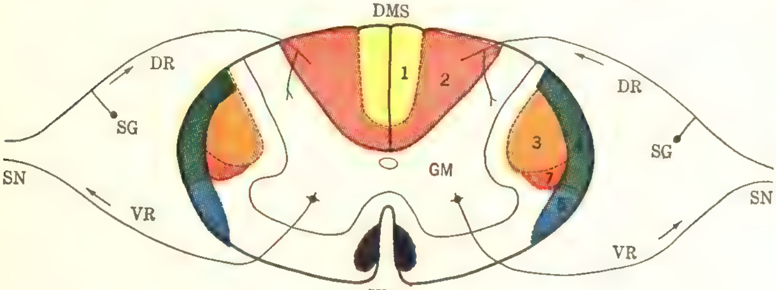


FIG. 112. — DIAGRAM TO SHOW GENERAL LOCATION OF SOME OF THE CONDUCTION PATHS AS SEEN IN A TRANSVERSE SECTION OF THE SPINAL CORD. *DMS*, dorsal median sulcus; *DR*, dorsal root; *GM*, gray matter; *SG*, spinal ganglion; *SN* spinal nerve; *VMS*, ventral median fissure; *VR*, ventral root. 1, fasciculus gracilis (tract of Goll); 2, fasciculus cuneatus (tract of Burdach); 3, lateral cerebrospinal fasciculus (crossed pyramidal tract); 4, dorsal spinocerebellar fasciculus; 5, ventrolateral spinocerebellar fasciculus (Gower's tract); 6, ventral cerebrospinal fasciculus, direct pyramidal tract); 7, rubrospinal tract.

the cord, *e.g.*, 3 and 6. Other funiculi (white in Fig. 112) are made up chiefly of short ascending and descending fibers beginning in one region of the spinal cord and ending in another.

The funiculi in the dorsal portion are chiefly ascending. Injury to these funiculi will interfere with the passage of sensory impulses and possibly (depending on location and extent of injury) loss of sensation in the parts from which the passage of impulses is blocked.

Locomotor ataxia or *tabes dorsalis* is a degeneration of the posterior fasciculi and posterior columns of the cord, resulting in disturbances of sensation, interference with reflexes, and consequently with movements such as walking, which after it is once learned is largely reflex. *Anterior poliomyelitis*, or infantile paralysis, is inflammation of the anterior areas of gray matter and results in paralysis of the parts supplied with motor nerves from the diseased portion of the cord.

Functions of the spinal cord. It is an important center of reflex action for the trunk and limbs and it consists of the principal conducting paths to and from the higher centers in the brain. From

the standpoint of function, the spinal cord may be regarded as consisting of more or less independent segments. Each segment is related by afferent and efferent nerve fibers to its own definite segmental area of the body.

SPINAL NERVES

There are thirty-one pairs of spinal nerves, arranged in the following groups, and named for the region of the vertebral column from which they emerge:

Cervical	8 pairs
Thoracic	12 pairs
Lumbar	5 pairs
Sacral	5 pairs
Coccygeal	1 pair

The first cervical nerves arise from the medulla oblongata and leave the neural canal between the occipital bone and the atlas. The other spinal nerves spring from the spinal cord, and all except the coccygeal pass out through the intervertebral foramina. The coccygeal passes from the lower extremity of the canal.

Mixed nerves. — The spinal nerves consist almost entirely of medullated nerve fibers, and are called mixed nerves because they contain both motor or efferent and sensory or afferent fibers. Each spinal nerve has two roots, a ventral root and a dorsal root. The fibers of the ventral root **arise from the gray matter** in the ventral column, and are direct prolongations from the cell bodies, consequently they are efferent fibers and convey impulses from the spinal cord to the periphery.

The fibers of the dorsal root arise from the **cells composing the enlargement** or **ganglion** of the dorsal root situated in the openings between the arches of the vertebræ. These cell-bodies give off a single fiber which divides in a T-shaped manner into two processes, one extends to a sensory end-organ of the skin, or muscles, tendons, joints, etc. The other extends into the spinal cord, forming the dorsal root of a spinal nerve.

The fibers that enter the cord directly do not all pass into the gray matter immediately, some extend upward and some downward in the white matter before doing so. Sooner or later they all enter the gray matter of the spinal cord or brain, where they form synapses with central or motor neurons.

It should be borne in mind that the ventral roots have their origin within the spinal cord and contain motor fibers. The dorsal roots have their origin outside the cord, *i.e.*, in the spinal ganglia,

and contain sensory fibers. The fibers connected with these two roots are collected into one bundle, and form a spinal nerve trunk just before leaving the canal through the intervertebral openings.[3]

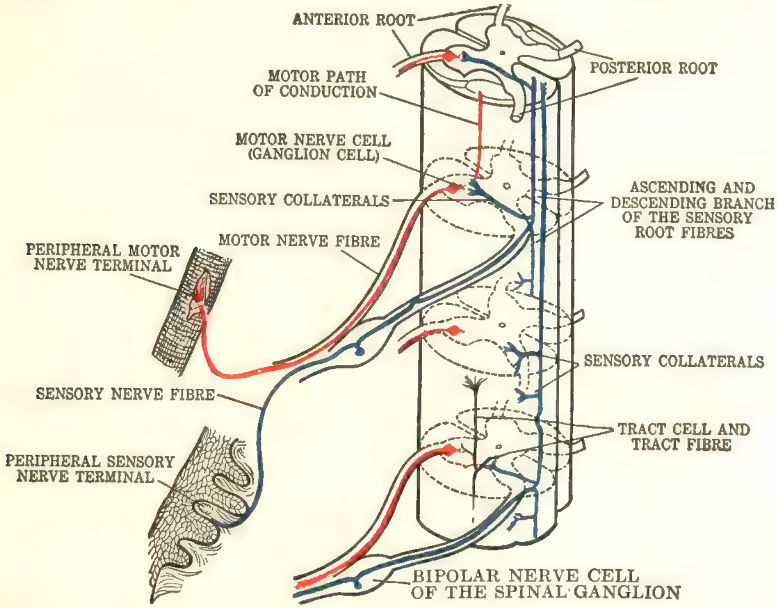


FIG. 113. — DIAGRAM OF MOTOR AND SENSORY PATHS OF CONDUCTION AND OF THE REFLEX ARCS OF THE SPINAL CORD.

Distribution of terminal branches of the spinal nerves. — After leaving the spinal column, each spinal nerve divides into two main trunks known as the ventral and dorsal branches. The dorsal branches supply the muscles and skin of the back of the head, neck, and trunk. The ventral branches supply the extremities and parts of the body in front of the spine. Each ventral branch connects with the autonomic ganglia by means of fibers which pass from the nerve to the ganglia and vice versa. Extending from the autonomic ganglia to their final distribution, these nerves, called autonomic nerves, form plexuses called the cardiac, the celiac or solar, the hypogastric, the pelvic, and the enteric. In passing to the viscera, muscles, skin, etc., terminal branches of these nerves follow the same pathways as the blood-vessels.

Names of peripheral nerves. — Many of the larger branches given off from the spinal nerves bear the same name as the artery

[3] The relations of the roots, fibers, and so forth, can best be understood from a study of Figs. 112 and 113.

which they accompany, or the part which they supply. Thus the radial nerve passes down the radial side of the forearm in company with the radial artery; the intercostal nerves pass between the ribs in company with the intercostal arteries. An exception to this is the two sciatic nerves which pass down from the sacral plexus, one on either side of the body near the center of each buttock, and the back of each thigh, to the popliteal region where each divides into two large branches which supply the leg and foot. Motor branches from these nerves pass to the muscles of the legs and feet and they receive sensory branches from the skin of the lower extremities.

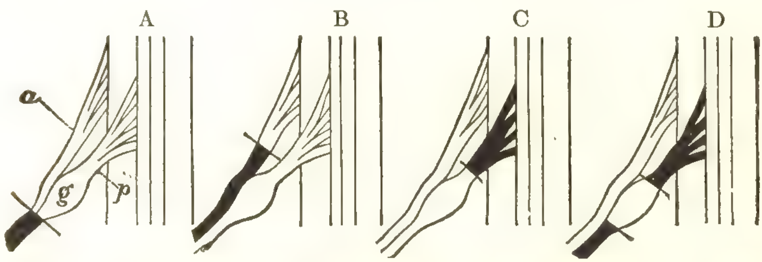


FIG. 114. — DEGENERATION OF SPINAL NERVES AND NERVE ROOTS AFTER SECTION. *A*, section of nerve trunk beyond the ganglion; *B*, section of anterior root; *C*, section of posterior root; *D*, excision of ganglion; *a*, anterior root; *p*, posterior root; *g*, ganglion. Black indicates the portion of the nerve which degenerates after section.

Degeneration and regeneration of nerves. — Since the cell body is essential for the nutrition of the whole cell, it follows that if the processes of a neuron are cut off, they will suffer from malnutrition and die. If, for instance, a spinal nerve be cut, all the peripheral part will die, since the fibers composing it have been cut off from their cell bodies situated in the cord, or in the spinal ganglia. The divided ends of a nerve that has been cut across readily reunite by cicatricial tissue, — that is to say, the connective tissue framework unites, but the cut ends of the fibers themselves do not unite. On the contrary, the peripheral or severed portion of the nerve fiber begins to degenerate, its medullary sheath breaks up into a mass of fatty molecules and is gradually absorbed, and finally the central fiber also disappears. In regeneration, the new fiber grows from the central end of the severed nerve fiber, and penetrating into the peripheral end of the neurilemma, grows along this as the fiber of the new nerve, the fiber after a time becoming surrounded with a medullary sheath. The nuclei of the neurilemma are thought to play an important part in both the degeneration and regeneration of the cut fiber. Restoration of function in the nerve may not occur for several months, during which time it is presumed the new nerve fibers are slowly finding their way along the course of those which have been destroyed. Since in a cranial nerve fiber the neurilemma is very much reduced or lacking, regeneration of an injured cranial nerve fiber rarely, if ever, occurs.

THE BRAIN

The brain is the largest and most complex mass of nervous tissue in the body. It is contained in the cavity formed by the bones of the cranium, and comprises five fairly distinct, though connected, parts: the cerebrum, the mid-brain, the cerebellum, the pons Varoli, and the medulla oblongata.

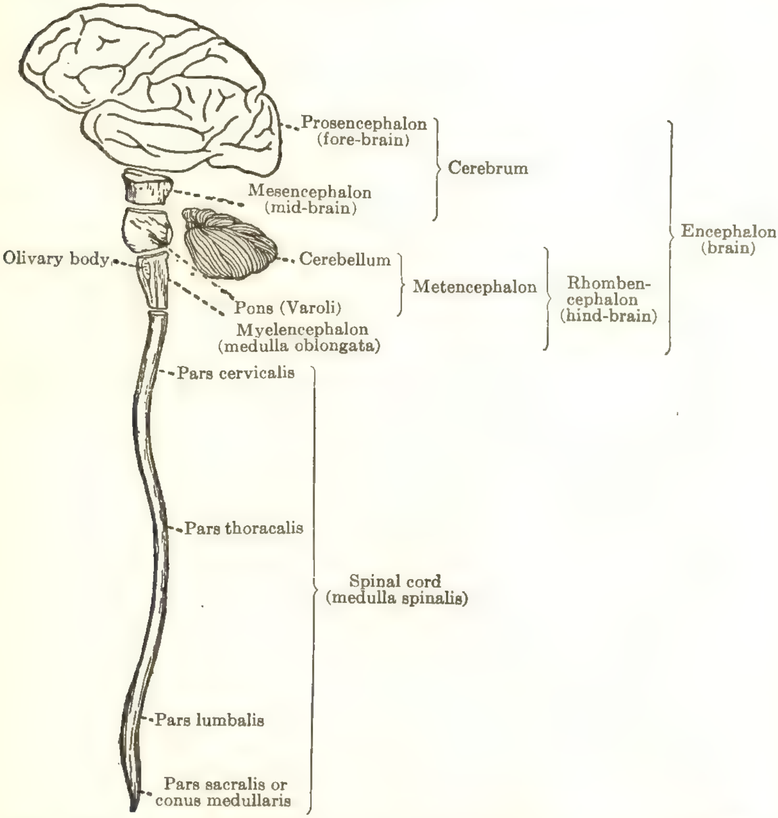


FIG. 115. — DIAGRAM ILLUSTRATING THE GROSS DIVISIONS OF THE CENTRAL NERVOUS SYSTEM. To some authors the word metencephalon refers to that part of the embryonic brain which develops into the cerebellum. To others it refers to the hind-brain. (Morris' *Anatomy*. Courtesy of P. Blakiston's Son & Co.)

In early embryonic life the brain consists of three hollow vesicles named the fore-brain or prosencephalon, the mid-brain or mesencephalon, and the hind-brain or rhombencephalon. During growth the cerebral hemispheres, their commissures, the first, second, and third ventricles are developed from the fore-brain;

the corpora quadrigemina, the cerebral peduncles, and the cerebral aqueduct (a tubular connection between the third and fourth ventricles) are developed from the mid-brain; the medulla oblongata, the pons Varoli, the cerebellum, and the included fourth ventricle are developed from the hind-brain.

Weight of the brain. — The average weight of the brain in the adult male is about 1380 gms. (48.6 oz.); in the adult female, about

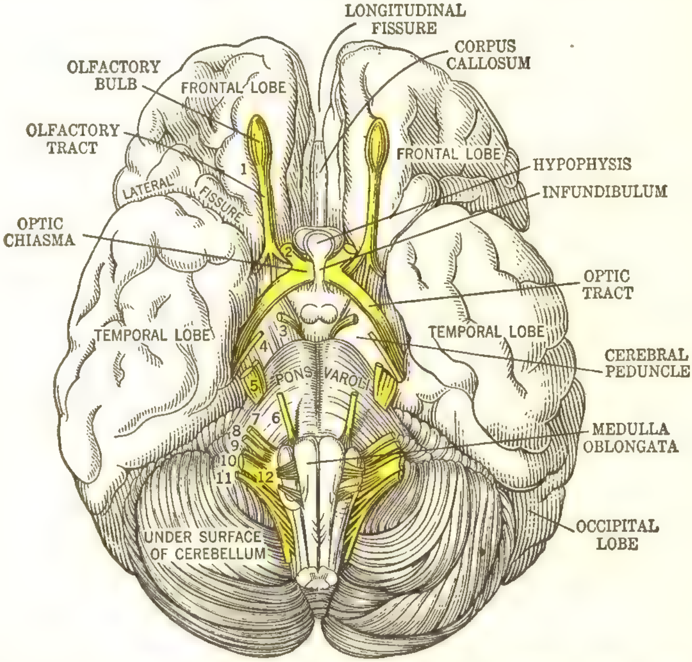


FIG. 116. — UNDER SURFACE OF THE BRAIN SHOWING THE MEDULLA OBLONGATA; THE PONS VAROLI, THE CEREBELLUM AND THE CEREBRUM; ALSO THE FISSURES, SULCI, AND CONVOLUTIONS. Projecting forward in the front are the two olfactory tracts and bulbs. The numerals indicate the cranial nerves. Note the *infundibulum.* To this the hypophysis or pituitary is attached. (Gerrish.)

1250 gms. (44 oz.). The weight of the brain is an indication of growth, which in early life depends upon the enlargement of the cells and their processes, the myelination of the nerve fibers, and an increase in the amount of neuroglia. The brain grows rapidly up to the fifth year and ceases to grow generally in the eighteenth or twentieth year. As age advances the brain loses weight, at first slowly, later more rapidly.

Development of the brain. — The development of the brain is not entirely a matter of growth but rather a matter of forming

new pathways, *i.e.*, new synapses, and a permanent modification of the synapses that are functionally active during various forms of mental activity. The nature of the brain protoplasm, and the use to which it is put, determines to some extent the length of time during which development may continue. Mental exercise keeps the brain active and capable of development, just as exercising a muscle tends to prevent atrophy or loss of function.

Cerebrum. — The cerebrum is by far the largest part of the brain. It is egg-shaped, and fills the whole of the upper portion of the skull. The entire surface, both upper and under, is composed of layers of gray matter, and is called the cortex. The bulk of the white matter in the interior of the cerebrum consists of

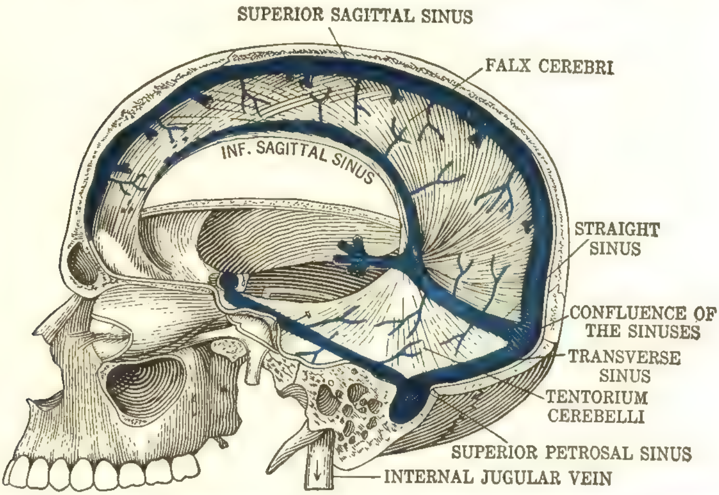


FIG. 117. — FALX CEREBRI AND TENTORIUM, LEFT LATERAL VIEW. (Gerrish.)

very small fibers running in three principal directions: (1) from above downward, (2) from the front backward, and (3) from side to side. The fibers link the different parts of the brain together, and connect the brain with the spinal cord.

Fissures and convolutions. — In early life the cortex of the cerebrum is comparatively smooth, but as time passes and the brain develops, the surface becomes covered with furrows which vary in depth. The deeper furrows are called *fissures*, the more shallow ones, *sulci*, and the ridges between the sulci are called gyri or *convolutions*. The fissures and sulci are infoldings of gray matter, consequently the more numerous and deeper they are, the greater is the amount of gray matter. The number and depth

of these fissures and sulci is thought to bear a close relation to intellectual power; babies and idiots have few and shallow furrows, while the brains of men of intellect are markedly convoluted. There are five important fissures which are always present.

(1) The *longitudinal cerebral fissure.* This extends from the back to the front of the cerebrum, and almost completely divides it into two hemispheres, the two halves, however, being connected in the center by a broad, transverse band of white fibers called the *corpus callosum.* A process of the dura mater extends down into this fissure and separates the two cerebral hemispheres. It is called the *falx cerebri,* because it is narrow in front, and broader behind, thus resembling a sickle in shape. Blood is returned from the brain in venous channels called sinuses. Two important sinuses are lodged between the layers of the falx cerebri. The superior sagittal sinus is contained in the upper border, and the inferior longitudinal sinus in the lower border. Fig. 117 shows these two sinuses, also the *straight sinus,* the *transverse* or *lateral,* and the *superior petrosal* sinuses of one side of the head. *Confluence of sinuses* (torcular Herophili[4]) is the name applied to the dilated extremity of the superior sagittal sinus.

(2) The *transverse fissure.* It is between the cerebrum and the cerebellum. A process of the dura also extends into this fissure, and covers the upper surface of the cerebellum and the under surface of the cerebrum. It is called the *tentorium cerebelli.*

(3) *Central Sulcus* or *Fissure of Rolando* (4) *Lateral cerebral fissure* or *Fissure of Sylvius* (5) *Parieto-occipital fissure*	There is one of each in each hemisphere. For location see Fig. 118.

Lobes of the cerebrum. — The longitudinal fissure divides the cerebrum into two hemispheres, and the transverse fissure divides the cerebrum from the cerebellum. The three remaining fissures assisted by certain arbitrary lines divide each hemisphere into five lobes. With one exception these lobes were named from the bones of the cranium under which they lie; hence they are known as: (1) **Frontal lobe.** (2) **Parietal lobe.** (3) **Temporal lobe.** (4) **Occipital lobe.** (5) **The Insula (Island of Reil).**

The **frontal** lobe is that portion of the cerebrum lying in front of the central sulcus, and usually consists of four main convolutions.

The **parietal** lobe is bounded in front by the central sulcus and behind by the parieto-occipital fissure.

[4] Herophilus, Greek physician, 335–280 B.C.

The **temporal** lobe lies below the lateral cerebral fissure and in front of the occipital lobe.

The **occipital** lobe occupies the posterior extremity of the cerebral hemisphere. When one examines the external surface of

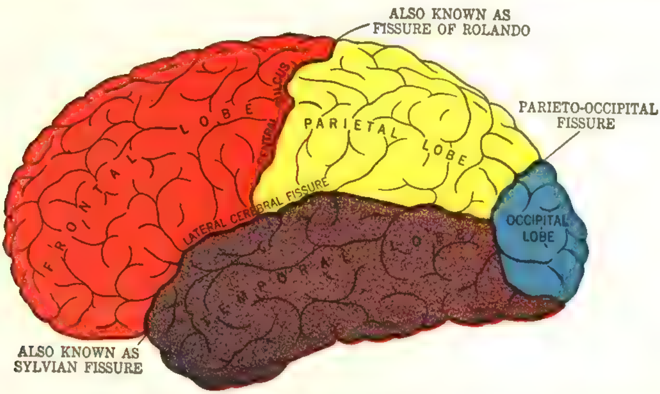


FIG. 118. — THE LOBES OF THE CONVEX SURFACE OF THE HEMISPHERE, LEFT SIDE. (Gerrish.)

the hemisphere, there is no marked separation of the occipital lobe from the parietal and temporal lobes that lie to the front; but when the surface of the longitudinal cleft is examined, the parieto-occipital fissure serves as a boundary anteriorly for the occipital lobe.

The **insula** (Island of Reil [5]) is not seen when the surface of the hemisphere is examined, for it lies within the lateral cerebral fissure, and the overlying convolutions of the parietal and frontal lobes must be lifted up before the insula comes into view.

Ventricles of the brain. — The brain is not a solid mass, but contains cavities called ventricles. The two lateral ventricles are situated one in each of the cerebral hemispheres under the mass of white fibers called the corpus callosum, which connects the two hemispheres. The *basal ganglia* of the brain are in the floor of the lateral ventricles. The third ventricle is behind the lateral ventricles but connected with each one by means of small openings called the foramina of Monro.[6] The fourth ventricle is in front of the cerebellum, behind the pons Varoli and the medulla. The third communicates with the fourth by means of a slender canal called the aqueduct of the cerebrum (aqueduct of Sylvius [7]). In

[5] Johann Christian Reil, Dutch anatomist, 1759–1813.

[6] Alexander Monro, Scottish anatomist, 1697–1767.

[7] Jacobus Sylvius, French anatomist, 1478–1555. A teacher of Andreas Vesalius.

the roof of the fourth ventricle are three openings, the median one being called the foramen of Magendie.[8] By means of these three openings, the ventricles communicate with the subarachnoid cavity, and the cerebrospinal fluid can circulate from one to the other.

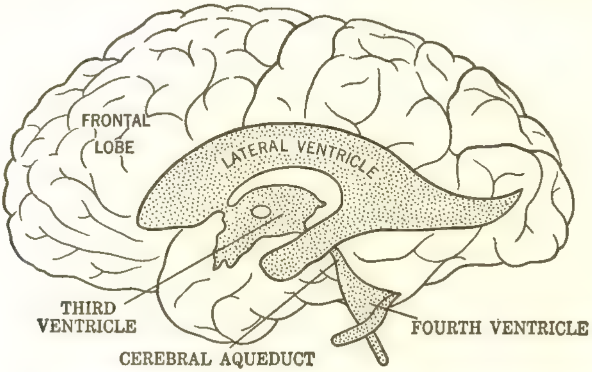


FIG. 119. — DIAGRAM TO SHOW THE VENTRICLES OF THE BRAIN IN POSITION AS SEEN FROM THE SIDE.

The so-called fifth ventricle is not a portion of the general cavity — not a true ventricle. It is a narrow space in front of the third having no connection with the other ventricles. The cavity of the lateral ventricles is large enough to occupy an appreciable space, and may become over-distended with cerebrospinal fluid in certain conditions of disease.

Functions of cerebrum. — In the higher vertebrates the cerebrum constitutes a larger proportion of the central nervous system than in the lower forms. It is especially large in animals that are capable of profiting by experience, hence has come to be regarded as the organ for the recall of memories of former experiences or associative memory. The nerve centers which govern all our mental activities, reason, intelligence, will, memory, and the higher emotions and feelings, are located in the cerebrum. It is the seat of consciousness, the interpreter of sensations, the instigator of voluntary acts, and exerts a controlling force (both accelerating and inhibiting) upon many reflex acts which originate as involuntary. Laughing, weeping, micturition, defecation, and many other acts might be cited as examples of the latter.

Localization of brain function. — As the result of numerous experiments on animals, and close observation of individuals suffering from wounds or cerebral disease, physiologists have been

[8] François Magendie, French physiologist, 1783–1855.

able to localize certain areas in the brain which control motor and sensory activity. They have also been able to gain some knowledge of the areas in the cerebrum which are concerned with the higher mental activities. But in no case is the control of a function limited to a single center, for practically all mental processes involve the discharge of nervous energy from one center to another. All parts of the cerebrum are connected. Change in the nervous activity of any part disturbs the equilibrium of the whole. Any activity, therefore, is the result of all the changes throughout the whole of the cortex. No one area acts alone to govern a particular function. As Herrick [9] says, such areas "are merely nodal points in an exceedingly complex system of neurons which must act as a whole in order to perform any function whatsoever."

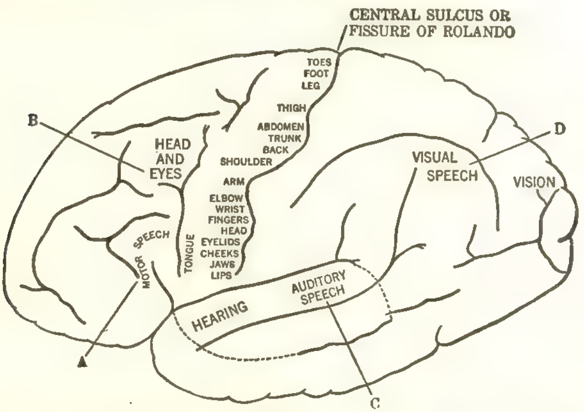


FIG. 120. — LOCALIZATION OF FUNCTION IN THE CEREBRAL CORTEX. The cortical area marked *A* is the motor speech center, damage to which causes loss of the word-forming power (motor aphasia). Damage to the cortical area marked *B* abolishes the power of writing, a form of sensory aphasia called agraphia. Damage to the center marked *C* produces word-deafness (sensory aphasia). Damage to the cortical area marked *D* produces word-blindness (sensory aphasia).

Names of areas. — The portions of the cerebrum which govern muscular movement are known as *motor areas,* the portions controlling sensation as the *sensory areas,* and those connected with the higher faculties, such as reason and will, as *association areas.*

Motor area. — The surface of the brain assigned to the function of motion is the precentral gyrus of the frontal lobe, *i.e.,* the gray matter immediately in front of the central sulcus. The centers which govern skeletal muscles are controlled by nerves arising in this area, and the special portions of the area in which

[9] C. Judson Herrick. An Introduction to Neurology.

the nerves supplying the various parts arise, *e.g.*, tongue, mouth, fingers, leg, can be studied in Fig. 120. Correct diagnosis and localization of brain injuries or disease are greatly aided by knowledge of the location of these areas.

Sensory area. — The sensory area occupies the portions of the cerebrum behind the central sulcus and can be divided into regions like those of the motor area just in front of the sulcus. The *visual area* is situated in the posterior part of the occipital lobe; the *auditory area* in the superior part of the temporal lobe; and the *olfactory* and *gustatory areas* are in the anterior part of the temporal lobe.

Location of speech areas. — There are four small areas in the cerebral cortex (marked *A*, *B*, *C*, *D*, in Fig. 120) which are known as the speech centers. They do not develop in both hemispheres. In right-handed persons they become fully developed in the left hemisphere, and in left-handed persons in the right hemisphere. The basis of language is a series of memory pictures. The mind must know and recall the names of things in order to mention them; it must have seen or heard things in order to describe them and to have learned the words to express these ideas. Even this is not enough. All these factors must work together under the influence of the center for articulate speech, which, as seen in Fig. 120, is in close connection with those for the larynx, tongue, and the muscles of the face. Injury to these centers results in some form of inability to speak,[10] to write,[11] or to understand spoken [12] or written [13] words. It is customary, therefore, to distinguish two types of aphasia, *i.e.*, motor and sensory. By *motor aphasia* is meant the condition of those who are unable to speak although there is no paralysis of the muscles of articulation. By *sensory aphasia* is meant the condition of those who are unable to understand written, printed, or spoken symbols of words, although the sense of vision and of hearing is unimpaired. These centers are really memory centers and aphasia is due to loss of memory either of words, or the meaning of words seen or heard, or of how to form letters.

Association areas. — The motor and sense areas form, so to speak, small islands which are surrounded on all sides by cerebral tissue in which as yet no definite functions have been localized. These regions are designated as association areas and are made up of association fibers which connect motor and sensory areas. Animals

[10] Aphasia.
[11] Agraphia.
[12] Word-deafness.
[13] Word-blindness.

that are capable of acquiring habits and conditioned reflexes have a greater development of these areas. It is thought that the association areas are plastic and register the effects of individual experience.

In the absence of the cerebrum, any animal must cease to be an association animal and become a reflex animal. In other words, all its actions are then removed from volition, in fact, from consciousness. All responses that depend upon memory of acquired and inherited experience have been destroyed.

The mid-brain. — The mid-brain (see Fig. 115) is a short constricted portion which connects the pons and cerebellum with the hemispheres of the cerebrum. It is directed upward and forward and consists of: (1) a pair of cylindrical bodies called the cerebral peduncles, which are made up largely of the descending and ascending fiber tracts from the cerebrum above, the cerebellum, medulla, and spinal cord below. (2) Four rounded eminences, called the corpora quadrigemina, which contain important correlation centers, and also contain nuclei concerned with motor coördination. (3) An intervening passage or tunnel, the cerebral aqueduct (aqueduct of Sylvius), which serves as a communication between the third and fourth ventricle.

Cerebellum. — The cerebellum occupies the lower and back part of the skull cavity. It is below the posterior portion of the cerebrum from which it is separated by the tentorium cerebelli, a fold of the dura mater, and behind the pons and the upper part of the medulla. It is oval in form, constricted in the center, and flattened from above downward. The constricted central portion is called the *vermis*, and the lateral expanded portions are called the hemispheres.

The surface of the cerebellum consists of gray matter and is not convoluted but is traversed by numerous furrows or sulci. The gray matter contains cells from which fibers pass and with which fibers entering the cerebellum from other parts of the brain form synapses. The cerebellum is connected with the cerebrum by the superior peduncles, with the pons by the middle peduncles, and with the medulla oblongata by the inferior peduncles. These peduncles are bundles of fibers. Incoming impulses from the motor centers in the cerebrum, from the semicircular canals of the inner ear, and from the muscles, enter the cerebellum by way of these bundles. Outgoing impulses are transmitted to the motor centers in the cerebrum, down the cord, and thence to the muscles.

Functions of cerebellum. — Embryological studies show that the cerebellum is developed as an outgrowth from the primary centers

of the semicircular canals in the medulla. The semicircular canals are receptors for static and equilibratory sensations. The cerebellum receives sensory impulses from the semicircular canals, from the sensory centers of the body-wall, and from the cerebral cortex. It sends nerve impulses into all the motor centers of the body-wall and helps to maintain equilibrium and the tone of the voluntary muscles. None of its activities come into consciousness. In man, injury to the cerebellum results in muscular weakness, loss of tone, and inability to direct the movements of the skeletal muscles. There may be difficulty in walking due to inability to control the muscles of the legs, or difficulty in talking due to lack of coördination of the muscles moving the tongue and jaw. The area of the body affected is determined by the location and extent of the injury to the cerebellum. Only parts of the body on the same side as the injury to the cerebellum are involved, unless both sides of the cerebellum are injured, and then the lack of muscle tone and coordination may be so great that the person is helpless.

The pons. — The pons (Varoli) [14] is situated in front of the cerebellum between the mid-brain and the medulla oblongata. It consists of interlaced transverse and longitudinal white nerve fibers intermixed with gray matter. The transverse fibers are those derived from the middle peduncles of the cerebellum, and serve to join its two halves. The longitudinal fibers connect the medulla with the cerebrum.

Function of pons. — The pons is a bridge of union between the two halves of the cerebellum and a bridge between the medulla and the cerebrum. The fifth (trigeminal) nerve emerges from the side of the pons near its upper border. The sixth (abducent), seventh (facial), and eighth (acoustic) nerves emerge in the superficial furrow which separates the pons from the medulla in front.

The medulla oblongata. — The medulla oblongata (spinal bulb) is continuous with the spinal cord which, on passing into the cranial cavity through the foramen magnum, widens into a pyramidal-shaped mass which extends to the lower margin of the pons. Externally the medulla resembles the upper part of the spinal cord, but the internal structure is different. All of the afferent and efferent tracts of the spinal cord are represented in the medulla, and many of them decussate or cross [15] from one side to the other,

[14] Also spelled pons Varolii. Costanzo Varolius, Italian anatomist, 1542–1575.

[15] In many cases of paralysis or convulsions, it is possible to locate the exact portion of the brain that is affected by close observation of the part of the body involved in the loss of function or convulsion.

while others end in the medulla. The nerve cells of the medulla are grouped to form nuclei, some of which are centers in which the cranial nerves arise. The motor fibers of the glossopharyngeal and of the vagus nerves, also the cranial portion of the accessory nerves, arise in the nucleus ambiguus. The hypoglossal nerve arises in the hypoglossal nucleus. Some of the nuclei are relay stations of sensory tracts to the brain, *e.g.*, the nucleus gracilis and nucleus cuneatus. Some serve as centers for the control of bodily functions, *e.g.*, the cardiac, vasoconstrictor, and respiratory centers.

Functions of the medulla oblongata. — The medulla serves as an organ of conduction for the passage of impulses between the cord and the brain. It contains (1) the cardiac, (2) the vasoconstrictor, and (3) the respiratory centers, and controls many reflex activities.

The cardiac inhibitory center consists of a bilateral group of cells lying in the medulla at the level of the nucleus of the vagus nerve. The fibers from this center accompany the vagi to the heart, and unite with the cardiac branches from the thoracolumbar nerves to form the cardiac plexus, which envelops the arch and ascending portion of the aorta. From the cardiac plexus the heart receives inhibitory fibers. It is believed this center constantly discharges impulses which tend to hold the heart to a slower rate than it would assume if this check did not exist. The activity of the heart is also affected by nerve impulses from the cardiac sympathetic nerves, which increase the rate of the heart beat and are called accelerator nerves. The inhibitory and accelerator fibers are true antagonists acting in opposite ways upon the heart.

The vasoconstrictor center consists of a bilateral group of cells in the medulla. Fibers from these cells descend in the cord, and at various levels they form synapses with spinal neurons in the ventral columns of gray matter. The spinal neuron serves as a preganglionic vasoconstrictor fiber, which terminates in a sympathetic ganglion. The path is further continued by a postganglionic fiber. The center and the fibers are in a state of constant activity and can be stimulated reflexly through sensory nerves. We must conceive of different cells in this center being connected by definite vasoconstrictor paths with different parts of the body, *e.g.*, the intestines or the skin. Further, the different parts of the center may be acted upon separately.

It is thought that the tonicity may be increased (excited) or decreased (inhibited). The fibers which, when stimulated, cause an excitation of the vasoconstrictor center, resulting in peripheral

vasoconstriction and rise of arterial pressure, are called pressor fibers. The fibers which, when stimulated, cause an opposite effect, *i.e.*, decrease the tone of the center, resulting in peripheral vasodilatation and fall of arterial pressure, are called depressor fibers.

Vasodilator fibers are efferent fibers which, when stimulated, cause a dilation of the arteries in the region supplied. Such fibers have been demonstrated in the facial and glossopharyngeal nerves, in the sympathetic nerves, and in the nervi erigentes. There is no experimental evidence that the vasodilators are in a state of tonic activity or that their activity is controlled from a center in the brain.

The respiratory center consists of a bilateral group of cells located in the medulla. The results of various experiments tend to support the belief that the respiratory center is automatic, that is, it possesses an inherent rhythmic activity similar to that of the heart muscle; but it is very sensitive to reflex stimulation. It is thought that the respiratory center is in connection with the sensory fibers of all the cranial and spinal nerves and with all the pathways from the cerebrum to the medulla. Stimulation of any of the sensory nerves of the body, *e.g.*, a dash of cold water, unusual sights, sounds, or emotional states, may affect the respiratory rate. The effect of the sensory nerves upon the activity of the respiratory center may be to increase or to decrease the rate or the amplitude of the respiration. Fibers which have a stimulating or augmenting effect are called respiratory pressor fibers, and those which have an inhibiting effect are called respiratory depressor fibers. It is possible that these fibers may by means of collateral connections produce effects upon the heart and blood-vessels as well as the respirations.

Inasmuch as normal respiration consists of an active inspiration and a passive expiration, it has been suggested that the respiratory center should be called the inspiratory center. However, we do have active expirations independent of the respirations proper, as in coughing, laughing, or the straining of defecation, micturition, or parturition, and as an integral part of the respirations in dyspnea. In dyspnea the coördinated activity of the expiratory muscles suggests the possibility of an expiratory center. There is no definite knowledge of such a center, but if it exists, it is probably located in the medulla.

In addition to the control of respiration and circulation many other reflex activities are effected through the medulla by means of the vagus and other cranial nerves, which originate in this region. Such activities are sneezing, coughing, vomiting, winking, the motions and secretions of the alimentary canal.

Meninges. — The brain and spinal cord are enclosed within three membranes. These are named from without inward: the dura mater, arachnoid, and pia mater.

The **dura mater** is a dense membrane of fibrous connective tissue containing a great many blood-vessels. The cranial and spinal portions of the dura mater differ, and are described separately, but it must be understood that they form one complete membrane. The *cranial dura mater* is arranged in two layers which are closely connected except where they separate to form sinuses for the passage of venous blood. The outer or endosteal layer is adherent to the bones of the skull and forms their internal periosteum. The inner or meningeal layer covers the brain and sends numerous prolongations inward for the support and protection of the different lobes of the brain. These projections also form sinuses that return the blood from the brain, and sheaths for the nerves that pass out of the skull. The *spinal dura mater* forms a loose sheath around the spinal cord, and consists of only the inner layer of the dura mater; the outer layer ceases at the foramen magnum, and its place is taken by the periosteum lining the vertebral canal. Between the spinal dura mater and the arachnoid is a potential cavity — the *subdural cavity* — which contains only enough fluid to moisten their contiguous surfaces.

The **arachnoid** is a delicate serous membrane placed between the dura mater and the pia mater, the cranial portion invests the brain loosely and with the exception of the longitudinal fissure it passes over the various convolutions and sulci and does not dip down into them. The spinal portion is tubular and surrounds the cord loosely. The *subarachnoid cavity* between the arachnoid and the pia mater is occupied by a spongy connective tissue and intercommunicating channels in which the subarachnoid fluid is contained.

The pia mater is a vascular membrane consisting of a plexus of blood-vessels held together by fine areolar connective tissue. The cranial portion invests the surface of the brain and dips down between the convolutions. The spinal portion is thicker and less vascular than the cranial. It is closely adherent to the entire surface of the spinal cord, and sends a process into the ventral fissure.

The cerebrospinal fluid. — The meningeal membranes and the spaces filled with fluid form a pad enclosing the brain and cord on all sides. Cerebrospinal fluid is probably secreted by the epithelial cells which cover the choroid plexuses of the

ventricles.[16] After filling the lateral ventricles it escapes by the foramen of Monro into the third ventricle, and thence by the aqueduct into the fourth ventricle. From the fourth ventricle the fluid is poured into the subarachnoid spaces through the medial foramen of Magendie and the two lateral foramina of Luschka.[17] From the subarachnoid spaces it is absorbed through the villi of the arachnoid into the dural sinuses; a small amount passes into the perineural lymphatics of the cranial and spinal nerves. Experimentally it has been found that dyes added to the cerebrospinal fluid travel along the course of certain cranial nerves, especially the olfactory. This loophole affords an opportunity for the entry of infection from the nasal cavities to the cerebral cavity.

The cerebrospinal fluid is colorless, alkaline, and has a specific gravity of 1.005 to 1.008. It consists of water with traces of protein,[18] some glucose, some salts as in blood plasma, a few lymphocytes, a relatively large quantity of carbon dioxide, and some pituitary hormones.

Infection and inflammation of the meninges of the brain will quickly spread to those of the cord. Such inflammation results in increased secretion, which, as it collects in a confined bony cavity, gives rise to symptoms of pressure, such as headache, slow pulse, slow respirations, and partial or complete unconsciousness. Cerebrospinal fluid may be removed by lumbar puncture. The needle by which the fluid is withdrawn is inserted between the third and fourth lumbar vertebræ into the subarachnoid space on the right side, the patient usually lying upon his left side with his knees drawn up, so as to arch the back. The fluid, or exudate, will contain all the products of the inflammatory process and the organisms causing it. Lumbar puncture is used for (1) diagnosis of meningitis, syphilis, intra-cranial pressure, and cerebral hemorrhage. (2) For therapeutic effect, (*a*) to relieve pressure in meningitis, hydrocephalus, uremia, and convulsions in children; (*b*) for the introduction of sera, such as antimeningitis serum, anti-pneumococcus serum, and tetanus antitoxin.

THE CRANIAL NERVES

There are twelve pairs of cranial nerves which emerge from the under surface of the brain and pass through the foramina in the base of the cranium. They are classified as motor, sensory, and mixed nerves, containing both motor and sensory fibers.

The origin of the cranial nerves is comparable to that of the spinal nerves. The motor fibers of the spinal nerves arise from cell-bodies

[16] The choroid plexuses are highly vascular folds or processes of the pia mater, which are found in the ventricles.

[17] Luschka, German anatomist, 1820–1875.

[18] If the membranes of the brain or cord are inflamed, there is an increase in the protein present.

in the ventral column of the cord, and the sensory or afferent fibers arise from cell bodies in the ganglia outside the cord. The motor or efferent cranial nerves arise from cell-bodies within the brain, which constitute their *nuclei of origin.* The sensory cranial nerves arise from groups of nerve cells outside the brain. These cells may form ganglia on the trunks of the nerves or they may be located in peripheral sensory organs, such as the nose and eyes. The central processes of the sensory nerves run into the brain and end by arborizing around nerve cells which form their *nuclei of termination.* The nuclei of origin of the motor nerves and the nuclei of termination of the sensory nerves are connected with the cerebral cortex.

Numbers and names. — The cranial nerves are named numerically according to the order in which they arise from the brain, and also by names which describe their nature, function, or distribution.

1.	Olfactory	Sensory	7.	Facial	Mixed
2.	Optic	Sensory	8.	Acoustic	Sensory
3.	Oculomotor	Motor	9.	Glossopharyngeal	Mixed
4.	Trochlear	Motor	10.	Vagus	Mixed
5.	Trigeminal	Mixed	11.	Accessory	Motor
6.	Abducent	Motor	12.	Hypoglossal	Motor

1. **The olfactory nerve** is the special nerve of the sense of smell. It arises from the central or deep processes of the olfactory cells of the nasal mucous membrane, where its fibers form a network, and are then collected into about twenty branches which pierce the cribriform plate of the ethmoid bone in two groups and form synapses with the cells of the olfactory bulb. From the olfactory bulb other fibers extend inward to centers in the cerebrum.

2. **The optic nerve** is the special nerve of the sense of sight. It consists of fibers derived from ganglionic cells in the retina. These cells are probably third in the series of neurons from the receptors to the brain. (See Fig. 256.)

3. **The oculomotor nerve** arises from a nucleus in the floor or the cerebral aqueduct. It supplies motor fibers to four of the extrinsic muscles of the eyeball, namely the superior rectus, inferior rectus, medial rectus, inferior oblique, and to two intrinsic muscles of the eyeball, namely the ciliaris and the sphincter pupillæ.

4. **The trochlear or pathetic nerve** arises from a nucleus in the floor of the cerebral aqueduct. It supplies motor fibers to the superior oblique muscle of the eye.

5. **The trigeminal or trifacial nerve** is the largest cranial nerve. It emerges from the brain by a small motor and a large sensory root.

The fibers of the motor root arise from two nuclei, a superior located in the cerebral aqueduct, and an inferior located in the upper part of the pons. It is uncertain whether the fibers from the superior nucleus are motor or sensory. The fibers of the sensory root arise from the semilunar ganglion (Gasserian) which lies in a cavity of the dura mater near the apex of the petrous portion of the temporal bone. The fibers from the two roots coalesce into one trunk and then subdivide into three large branches: (1) the ophthalmic, (2) the maxillary, and (3) the mandibular.

The ophthalmic branch is the smallest and is a sensory nerve. It divides into three branches, the lacrimal, the frontal, the nasociliary; and communicates with the oculomotor, the trochlear, and the abducent. It supplies branches to the cornea, ciliary body, and iris; to the lacrimal gland and conjunctiva; to part of the mucous membrane of the nasal cavity; to the skin of the eyelid, eyebrow, forehead, and nose.

The maxillary, the second division of the trigeminal, is also a sensory nerve. It divides into many branches, which are distributed to the dura mater, the forehead, the lower eyelid, the lateral angle of the orbit, the upper lip, gums, and teeth of upper jaw, mucous membrane and skin of the cheek and of the nose.

The mandibular is the largest of the three divisions of the trigeminal. It is both a sensory and a motor nerve; divides into many branches and distributes them to the temple, the pinna of the ear, the lower lip, the lower part of the face, the teeth and gums of the mandible, and the muscles of mastication. It also supplies the mucous membrane of the anterior part of the tongue with the lingual nerve.

6. **The abducent nerve** arises in a small nucleus lying beneath the floor of the fourth ventricle. It is a motor nerve and supplies fibers to the lateral recti muscles of the eyes.

7. **The facial nerve** is a mixed nerve, consisting of a motor and a sensory part. The motor fibers arise from a nucleus in the lower part of the pons. The sensory fibers arise from a ganglion (geniculate) on the facial nerve. The single process of the ganglionic cells divides in a T-shaped manner into central and peripheral fibers. The central fibers pass into the medulla oblongata and end in the terminal nucleus of the glossopharyngeal nerve. The peripheral fibers form the sensory root and emerge from the brain with the motor root. Behind the ramus of the mandible the facial nerve divides into many branches. Motor fibers are supplied to the muscles of the face, part of the scalp, the pinna, and muscles of the

neck. Vasodilator fibers are supplied to the submaxillary and sublingual glands. Sensory fibers are supplied to the anterior two-thirds of the tongue (taste) and a few to the region of the middle ear.

8. **The acoustic (auditory) nerve** is a sensory nerve and contains two distinct sets of fibers, which differ in their origin, destination, and function. One set of fibers is known as the *cochlear nerve,* or nerve of hearing. These fibers originate in the spinal ganglion of the cochlea. The other is the *vestibular nerve,* or nerve for the maintenance of equilibrium. The fibers originate in the vestibular ganglion of the vestibular portion of the ear.

9. **The glossopharyngeal nerve** contains both sensory and motor fibers and is distributed, as its name indicates, to the tongue and pharynx. The sensory fibers arise from the superior and petrous ganglia, which are situated on the trunk of the nerve, the former in the jugular foramen, the latter in the petrous portion of the temporal bone. The motor fibers arise from the nucleus ambiguus, common to this and the tenth nerve, which is situated in the medulla. This nerve supplies sensory fibers to the mucous membrane of the fauces, tonsils, pharynx, and the posterior third of the tongue, giving the sense of taste. It also supplies motor fibers to the muscles of the pharynx and secretory fibers to the parotid gland.

10. **The vagus or pneumogastric nerve** has a more extensive distribution than any of the other cranial nerves, since it passes through the neck and thorax to the abdomen. It is a mixed nerve. Its motor fibers arise from the nucleus ambiguus. These fibers supply the muscles of the pharynx, larynx, trachea, heart, mouths of the large arteries and veins, aortic arch, esophagus, stomach, small intestine, pancreas, liver, spleen, ascending colon, kidneys, and visceral blood vessels. The heart is supplied with inhibitory fibers, and the gastric and pancreatic glands with secretory fibers. Its sensory or afferent fibers arise from cells of the jugular ganglion and from the ganglion nodosum located on the trunk of the nerve. The afferent or sensory fibers are distributed to the mucous membrane of the larynx, trachea, and lungs, and to the mucous membrane of the esophagus, stomach, intestines, and gall-bladder.

11. **The accessory nerve** is a motor nerve, consisting of two parts, a cranial and a spinal. The cranial part arises from the nucleus ambiguus in the medulla, and its fibers are distributed to the pharyngeal and superior laryngeal branches of the vagus. The spinal part arises from the spinal cord as low as the fifth cervical

nerve, ascends, enters the skull through the foramen magnum, is directed to the jugular foramen, through which it passes, and descends to the sternocleidomastoid and trapezius muscles.

12. **The hypoglossal nerve** arises from the hypoglossal nucleus in the medulla. It is a motor nerve supplying the muscles of the tongue and hyoid bone.

The Autonomic System

The division of the nervous system into the cerebrospinal system and the autonomic system is based on a difference in function and not on an actual anatomical separation. The autonomic system possesses a certain independence of the cerebrospinal system. It regulates and controls the visceral activities on which life depends. Ordinarily we are not even conscious of these activities, except as they contribute in a general way to a sense of well-being. Most of the centers controlling these processes are located within the central nervous system, but reflex and coördinating centers occur in the walls of the viscera and these centers are capable of controlling such activities as the contractions of the stomach, the peristalsis of the intestines, glandular activity, etc., without impulses emanating from the central nervous system. Not only is this true, but some of the visceral functions can be performed quite apart from any nervous control whatever. The heart muscle contracts automatically; some of the glands are excited to secretion by chemical substances dissolved in the blood, as, for instance, the secretion of pancreatic fluid due to the stimulus of the hormone *secretin*. Even though such activities are not directly excited by the nervous system, they may be brought under the control of the nervous system, because in all the visceral functions the non-nervous and the nervous coöperate in a most intimate way.

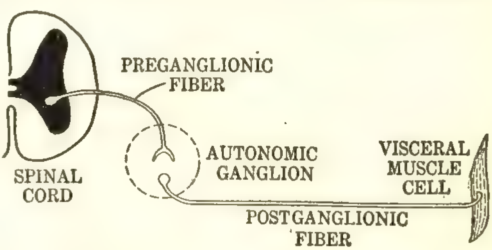
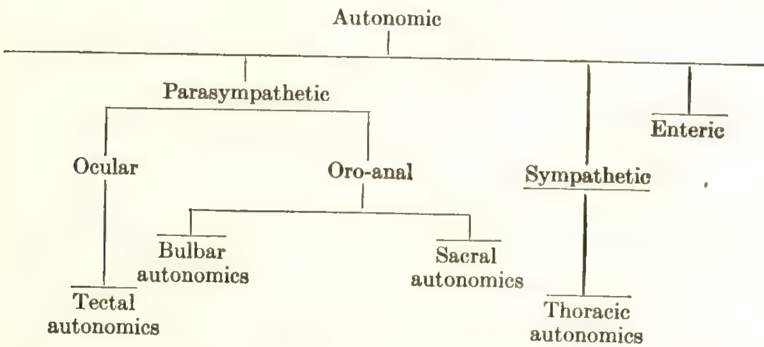


FIG. 121. — DIAGRAM TO SHOW THE RELATION OF THE PREGANGLIONIC AND POSTGANGLIONIC FIBERS OF THE AUTONOMIC SYSTEM.

In the autonomic system two neurons connect the central nervous system and the organ to be stimulated. The fiber of a neuron belonging to the *central nervous system* extends to an *autonomic* ganglion and ends around the dendrons of an autonomic neuron.

The fiber of the second neuron passes to the organ to be innervated. The fiber of the first neuron is called *preganglionic*, and the fiber of the second neuron is called *postganglionic*. Careful study of Fig. 121 will make this clear.

Much confusion has arisen because of the various names used to describe this system, and the various ways in which it has been classified. The terms sympathetic, parasympathetic, visceral, vegetative, splanchnic, involuntary, and autonomic are used in different ways in various texts. Langley's classification follows:



According to this classification the autonomic nerves fall into three classes, parasympathetic, sympathetic, and enteric. The parasympathetic system is also called the craniosacral system. The sympathetic system is also called the thoracolumbar system. Craniosacral system and thoracolumbar system are used in this book.

Craniosacral or parasympathetic system. — This includes all the fibers which arise from the mid-brain (tectal autonomics), from the medulla (bulbar autonomics), and from the sacral region of the cord (sacral autonomics).

The tectal autonomics arise from roots in the mid-brain, send preganglionic fibers with the oculomotor nerve into the orbit, and pass to the ciliary ganglion, where they terminate by forming synapses with motor neurons whose axons (postganglionic fibers) proceed as the short ciliary nerves to the eyeballs. These fibers convey motor impulses to the circular muscle of the iris and the ciliary muscle of the eye.

The bulbar autonomics arise from roots in the medulla which emerge in the seventh, ninth, tenth, and eleventh cranial nerves. Fibers of the facial and glossopharyngeal nerves supply vasodilator fibers to the glands and blood-vessels of the nose and mouth. Pre-

ganglionic fibers of these nerves terminate in some of the ganglia which are found in this region, namely, the spheno-palatine, otic,[19] submaxillary, and sublingual. The autonomic fibers that arise with the vagus (and the accessory) convey motor impulses to the plain muscular tissue of the larynx, esophagus, stomach, small intestine, and part of the large intestine; secretory impulses to the stomach, and pancreas; and inhibitory impulses to the heart. Preganglionic fibers of these nerves probably terminate in the local ganglia in or near the organs which they innervate.

The sacral autonomics include autonomic fibers which emerge from the cord. Neurons of the second, third, and fourth sacral spinal nerves send fibers to the pelvis where they are collected together to form the pelvic nerve, or *nervus erigens,* which proceeds to the pelvic plexus from which postganglionic fibers are distributed to the pelvic viscera. Motor fibers pass to the smooth muscle of the descending colon, rectum, anus, and bladder. Vasodilator fibers are distributed to these organs, and to the external genitals (penis, clitoris, vulva), while inhibitory fibers pass to the smooth muscles of the external genitals. The parts supplied by these nerves are indicated in Fig. 122.

Thoracolumbar or sympathetic system. — This includes: (1) centers in the cervical, thoracic, and lumbar regions of the cord; and preganglionic fibers arising in these centers; (2) the sympathetic ganglia and their fibers; (3) the great plexuses that are stimulated by impulses from the sympathetic ganglia.

The sympathetic centers in the spinal cord are composed of groups of cells lying in the lateral columns of the gray matter of the cord. They give rise to preganglionic fibers which make their first termination in one of the sympathetic ganglia.

The sympathetic ganglia, also known as the thoracolumbar, consist of a chain of ganglia which lie along the ventro-lateral aspects of the vertebral column, extending from the base of the skull to the coccyx. They are grouped as cervical, thoracic, lumbar, and sacral, and, except in the neck, they correspond in number to the vertebræ against which they lie:

Cervical	*Thoracic*	*Lumbar*	*Sacral*
3 pairs	10–12 pairs	4 pairs	4–5 pairs

They are connected with each other by nerve fibers called ganglia cords, and with the spinal nerves by branches which are called *rami communicantes.* In the thoracic and lumbar regions these con-

[19] Otic, of or pertaining to the ear.

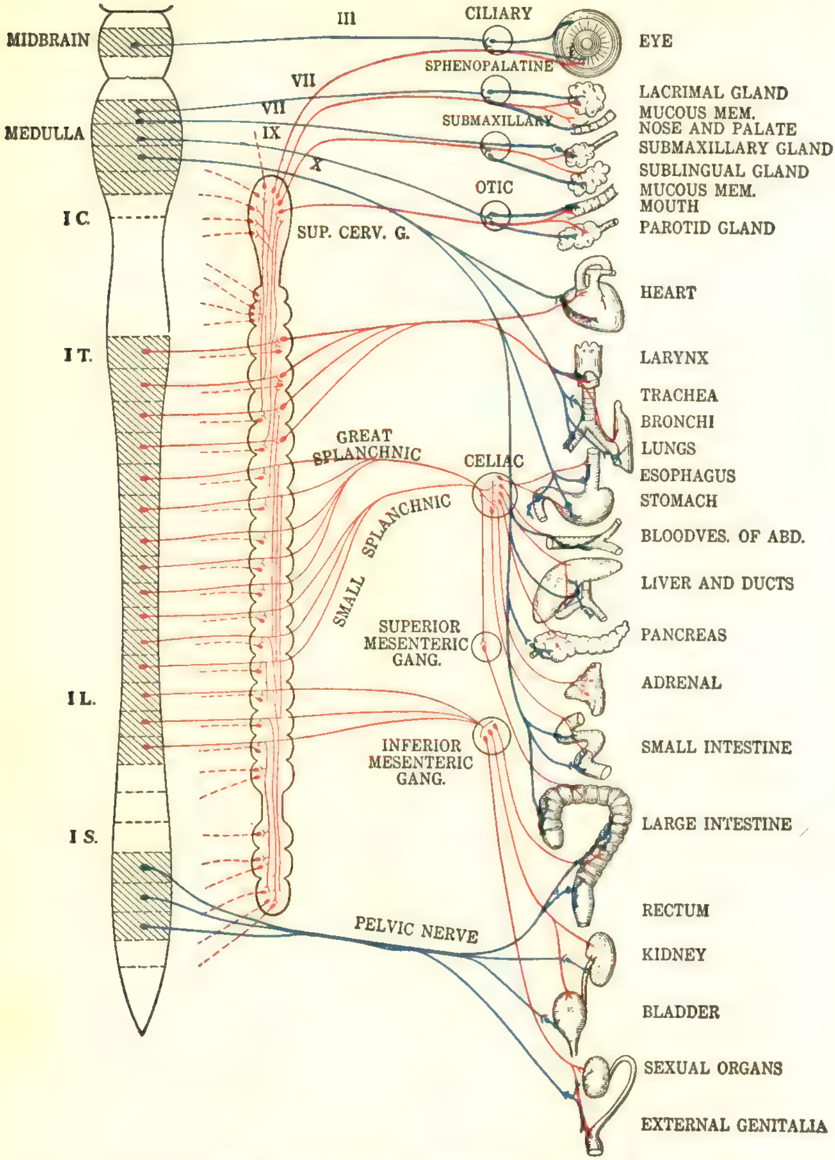


FIG. 122. — DIAGRAM OF EFFERENT AUTONOMIC NERVOUS SYSTEM. Blue, cranial and sacral outflow. Red, thoraco-lumbar (thoraco-humoral) outflow. Postganglionic fibers to spinal and cranial nerves to supply vasomotors to head, trunk, and limbs, motor fibers to smooth muscles of skin, and fibers to sweat glands. (Modified from Meyer & Gottlieb.)

nections consist of two rami, one white and the other gray. (See Fig. 123.) The white ramus consists of myelinated motor fibers passing between the central nervous system and the sympathetic. The gray ramus consists of nonmyelinated fibers that are the axons of the cells of the sympathetic ganglia distributed chiefly with the peripheral branches of the spinal nerves. On entering the ganglion, the fiber may end around a sympathetic neuron, from which a

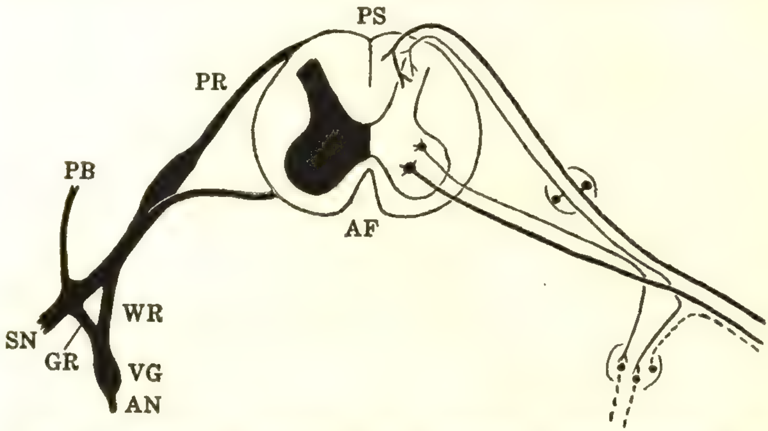


FIG. 123. — DIAGRAM OF SPINAL CORD AND SPINAL NERVE SHOWING SOME OF ITS MAIN BRANCHES. *AF*, anterior fissure; *AN*, autonomic or sympathetic nerve; *GR*, gray ramus communicans; *PB*, posterior branch of spinal nerve; *PR*, posterior root; *PS*, posterior sulcus; *SN*, spinal nerve; *VG*, vertebral ganglion; *WR*, white ramus communicans. On the right a few of the nerve cells which compose the spinal nerve are shown.

postganglionic fiber joins the spinal nerve, or it may pass up or down in the chain for some distance before ending around a sympathetic neuron. Just as the connector elements (tracts) in the spinal cord may ascend or descend, so the connector elements in the autonomic system ascend or descend in the sympathetic trunks.

The fibers that are distributed to the skin areas of the body — head, limbs, and trunk — return by way of the gray rami to the various spinal nerves, and are distributed with these nerves, the final distribution being somewhat different for the different varieties of fibers — vasomotor, sweat, and pilomotor. The fibers that are distributed to the blood-vessels, glands, and walls of the viscera take a different course. For the head region the fibers after entering the sympathetic chain pass upward and end in the *superior cervical ganglion;* from this ganglion postganglionic fibers emerge by the various plexuses that arise from this ganglion. Fibers from

the fifth to the tenth and sometimes the eleventh thoracic ganglia converge to form two main nerve trunks, the *great splanchnic* and the *small splanchnic.* Branches from these nerves form synapses in the celiac plexus.

The great plexuses of the thoracolumbar system consist of ganglia and fibers derived from the lateral chain ganglia and the spinal cord. They are situated in the thoracic, abdominal, and pelvic cavities, and are named the cardiac, celiac, and hypogastric plexuses.

(*a*) *The cardiac plexus* is situated at the base of the heart, lying on the arch and the ascending portion of the aorta. From it the heart receives inhibitory fibers.

(*b*) *The celiac plexus* (solar plexus) is situated behind the stomach, between the suprarenal glands. It surrounds the celiac artery and the root of the superior mesenteric artery. It consists of two large ganglia and a dense network of nerve fibers uniting them. It receives the greater and lesser splanchnic nerves of both sides, some fibers from the vagi, and gives off numerous secondary plexuses along the neighboring arteries. The names of the plexuses indicate the arteries which they accompany and the organs to which they distribute branches.

Phrenic	Superior Gastric	Spermatic
Hepatic	Suprarenal	Superior Mesenteric
Splenic	Renal	Abdominal Aortic
		Inferior Mesenteric

These nerves form intricate networks and any one organ may receive branches from several nerves. This increases the number of pathways and connections between the organs.

(*c*) *The hypogastric plexus* is situated in front of the last lumbar vertebra and the promontory of the sacrum. It is formed by the union of numerous filaments which descend on either side from the aortic plexus and from the lumbar ganglia; below it divides into two pelvic plexuses.

The enteric system.— This system includes the myenteric (Auerbach's) [20] and submucous plexuses (Meissner's) [21] of the digestive tube. They extend from the upper levels of the esophagus to the anal canal. The myenteric plexus is situated between the longitudinal and circular muscles. The submucous plexus lies in the submucosa. These plexuses are intimately connected with each other through numerous links.

[20] Leopold Auerbach, German anatomist, 1828–1897.
[21] Georg Meissner, German histologist, 1829–1903.

Functions of the autonomic system. — The autonomic system innervates (1) all plain muscular tissue in the body, (2) the heart, and (3) the glands. Recent work indicates that the skeletal muscles also receive autonomic fibers. The ganglia serve as relay stations for many of the impulses passing from the cerebrum, medulla, or spinal cord, but for the most part they act independently of these influences.

In general every organ has a double autonomic innervation, one from the thoracolumbar system and one from either the cranial or sacral autonomic system. The functions of these two sets are usually antagonistic. With the exception of nicotine, which paralyzes all autonomic ganglia, most drugs which act on the autonomic system affect principally either the craniosacral system, *e.g.*, atropine, pilocarpine, and physostigmine, or the thoracolumbar system, *e.g.*, epinephrin, ergotoxin, and cocaine.

A few examples of this antagonistic action are listed so that the results following stimulus of these two systems may be compared.

Craniosacral	Thoracolumbar
1. Contracts the pupils.	1. Dilates pupils.
2. Contracts ciliary muscles, so that eyes are accommodated to see objects near at hand.	2. Lessens tone of ciliary muscles, so that eyes are accommodated to see objects at a distance.
3. Contracts bronchial tubes.	3. Dilates bronchial tubes.
4. Slows and weakens the action of heart.	4. Quickens and strengthens the action of heart.
5. Dilates blood-vessels in nose, salivary glands, and pharynx.	5. Contracts blood-vessels supplied with vasoconstrictor nerves.
6. Increases contractions of gastro-intestinal tract.	6. Lessens contractions of gastro-intestinal tract.
7. Increases secretions of glands.	7. Decreases secretions of glands.
8. Increases uterine contractions.	8. Lessens uterine contractions.

The thoracolumbar system is strongly stimulated by pain and unpleasant excitement such as rage and terror. The animal responses to rage and terror are fight and flight, and the conditions brought about by stimulating the thoracolumbar system are such as to favor these responses, *i.e.*, the bronchial tubes are relaxed, and rapid breathing is rendered easier; the contraction of the blood-vessels in the stomach and intestines, and the increased heart action, forces more blood into the skeletal muscles, and thus provides them with the extra oxygen and fuel needed for increased muscular activity; the supply of glucose from the liver is also increased, thus furnishing more fuel; and increased perspiration tends to lessen body heat and prevents a rise in temperature. All of these responses are closely connected with the suprarenal glands,

which secrete a substance called epinephrin, which secretion is increased in amount when the thoracolumbar system is stimulated.

Interdependence of the craniosacral and thoracolumbar systems. — Marked stimulation of one system, or even part of one system, is likely to stimulate some part of the other system, thus checking excessive stimulation with the bad results that might follow. For example: stimulation of the part of the vagus that supplies the bronchial tubes may cause such marked contraction of the tubes that interference with breathing, pain, and distress may result; this in turn stimulates the thoracolumbar system to lessen the contraction of the tubes. Or another example: the afferent branch of the vagus that is connected with the heart is stimulated by marked contraction of the blood-vessels, and this transmits: (1) inhibitory impulses to the heart, thus slowing its action; (2) inhibitory impulses to the vasoconstrictor center, thus lessening the contraction of the vessels.

In certain cases of anginal pain, in cases of spastic paralysis, characterized by exaggerated tone of the muscles, and in diseases of the blood-vessels characterized by exaggerated vasoconstrictor tone, sympathetic ganglionectomy, and ramisection are sometimes practiced. *Sympathetic ganglionectomy* consists of the removal of one or more of the ganglia of the sympathetic trunk, in order to insure complete interruption of all peripheral connections.

Sympathetic ramisection consists in section of the communicating rami connecting one or more ganglia of the sympathetic trunk with the spinal nerves. For instance, removal of the second, third, and fourth lumbar sympathetic ganglia, or section of the communicating rami joining the nerves of the lumbosacral plexus, results in paralysis of the vasoconstrictor nerves supplying the vessels of the lower extremities. Consequently the vessels dilate and the blood supply to the extremity is increased. There is a rise in surface temperature, increased redness of the skin, and an increased production of heat. See *Sympathectomy in the Treatment of Various Diseases* by Winchell McK. Craig, M. D., *American Journal of Nursing*, May, 1931.

SUMMARY

Spinal Cord
- Located in spinal canal.
- Extends from foramen magnum to second lumbar vertebra.
- Average length about 45 cm.
- Consists of
  - Gray matter in form of H enclosed within white matter.
  - On each side white matter is in funiculi
    - Anterior or ventral.
    - Lateral.
    - Posterior or dorsal.
- **Fissures**
  - Ventral divides front portion in lateral halves.
  - Dorsal sulcus divides back portion in lateral halves.

- **Spinal Cord**
  - **Transverse commissure** — connects lateral halves.
  - **Central canal** — center of isthmus.
  - **Membranes**
    - **Pia mater** — inner membrane, closely invests spinal cord.
    - **Arachnoid** — middle membrane.
    - **Dura mater** — outer membrane.
  - **Functions**
    - Important center of reflex action for the trunk and limbs.
    - Consists of the principal conducting paths to and from the higher centers in the brain.

- **Spinal Nerves**
  - **Number**

Cervical	8 pairs
Thoracic	12 pairs
Lumbar	5 pairs
Sacral	5 pairs
Coccygeal	1 pair
	31 pairs

  - **Variety**
    - Medullated.
    - Mixed
      - Sensory.
      - Motor.
  - **Origin** — two roots
    - Ventral in gray matter of cord.
    - Dorsal in spinal ganglia.
  - **Distribution** — two trunks
    - Ventral supplies extremities, and parts of body in front of spine.
    - Dorsal, supplies muscles and skin of back of head, neck, and trunk.

- **Brain Consists of 3 Hollow Vesicles in Early Embryonic Life**
  1. **From the Prosencephalon or Fore-brain** — The cerebral hemispheres, their commissures, the first, second, and third ventricles are developed.
  2. **From the Mesencephalon or Mid-brain** — The corpora quadrigemina, the cerebral peduncles, and the cerebral aqueduct are developed.
  3. **From the Rhombencephalon or Hind-brain** — The medulla oblongata, the pons Varoli, and the cerebellum are developed.

- **Brain**
  - Located in cranial cavity.
  - Covered by meninges — same as spinal cord.
  - **Divisions**
    - Cerebrum.
    - Mid-brain.
    - Cerebellum.
    - Pons Varoli.
    - Medulla Oblongata.

- **Average Weight of Human Brain**
  - Male — about 1380 grams.
  - Female — about 1250 grams.

- **Development of Brain**
  - Not entirely a matter of growth, but of forming new pathways.
  - Nature of brain protoplasm and use to which it is put determine length of time during which development continues.
  - Mental exercise tends to keep brain active.

- **Cerebrum**
  - **Description**
    - Ovoid in shape.
    - Fills upper portion of skull.
    - Gray matter on outside
      - Fissures.
      - Sulci.
      - Convolutions.
    - White matter on inside.
    - **Fissures**
      - Longitudinal cerebral fissure.
      - Transverse fissure.
      - Central sulcus or Rolandic.
      - Lateral cerebral or Sylvian.
      - Parieto-occipital.
    - **Lobes**
      - Frontal.
      - Parietal.
      - Occipital.
      - Temporal.
      - Insula, or Island of Reil.
    - **Ventricles**
      - Lateral ventricles (two).
      - Third ventricle.
      - Fourth ventricle.
      - Fifth ventricle — not a true ventricle
  - **Function**
    - Governs all mental activities
      - Organ of associative memory.
      - Reason.
      - Intelligence.
      - Will.
      - Higher emotions.
      - Seat of consciousness.
      - Interpreter of sensations.
      - Instigator of voluntary acts.
      - Exerts a controlling force on reflex acts.
  - **Names of Areas**
    - **Motor area** — in front of central sulcus.
    - **Sensory areas**
      - Behind the central sulcus.
      - Visual — occipital lobe.
      - Auditory — superior part of the temporal lobe.
      - Olfactory, Gustatory — anterior part of temporal lobe.
    - **Association areas** — cerebral tissue surrounding motor and sensory areas, in which as yet no definite functions have been localized.

- **Mid-brain**
  - **Description**
    - Short, constricted portion connects pons and cerebellum with the hemispheres of the cerebrum.
    - Consists of
      - Pair of cylindrical bodies called cerebral peduncles.
      - Four rounded eminences called the corpora quadrigemina.
      - The cerebral aqueduct.

- **Cerebellum**
  - **Description**
    - Oval in form, constricted in center.
    - Central portion called vermis.
    - Lateral portions called hemispheres.
    - Gray matter on exterior.
    - White matter in interior.
    - Connected with cerebrum by superior peduncles.
    - Connected with pons by middle peduncles.
    - Connected with medulla by superior peduncles.
  - **Function**
    - Helps to maintain equilibrium and the tone of voluntary muscle.
- **Pons Varoli**
  - **Description**
    - Situated between the mid-brain and the medulla oblongata. Consists of interlaced transverse and longitudinal white fibers mixed with gray matter.
  - **Function**
    - Connects two halves of cerebellum and also medulla with cerebellum.
    - Place of exit for trigeminal, abducent, facial, and acoustic nerves.
- **Medulla Oblongata**
  - **Description**
    - Pyramidal-shaped mass, upward continuation of cord. Afferent and efferent tracts of spinal cord represented. Many of them cross from one side to the other in the medulla, some end in medulla.
    - Gray matter forms nuclei.
    - Nuclei serve as
      - Centers in which cranial nerves arise, centers for control of bodily functions.
      - Relay stations of sensory tracts to brain.
  - **Function**
    - Vital centers
      - Cardiac center.
      - Vasoconstrictor center.
      - Respiratory center.
    - Controls such reflex activities as
      - Sneezing.
      - Coughing.
      - Vomiting.
      - Winking.
      - Motions and secretions of alimentary canal.
- **Meninges or Membranes of Brain and Cord**
  - **Cranial dura mater** — arranged in two layers. Outer layer adherent to bones of skull; inner layer covers the brain.
  - **Spinal dura mater** — consists of only the inner layer, forms a loose sheath around the cord.
  - **Arachnoid** — serous membrane placed between the dura mater and pia mater of both brain and cord.
  - **Cranial pia mater** — vascular membrane, invests brain, and dips down into crevices and depressions.
  - **Spinal pia mater** — is closely adherent to cord and sends a process into the anterior fissure.
- **Cerebrospinal Fluid**
  - Found in meningeal spaces of brain and cord and ventricles of the brain.
  - Formed in choroid plexuses of the ventricles from blood.
  - Clear, limpid fluid, specific gravity 1.005 to 1.008.
  - Contains traces of protein, glucose, salts, lymphocytes, carbon dioxide, and pituitary antacoids.
  - **Function**
    - Nutritive medium for nerve cells.
    - Acts as a water-bed.

- **Autonomic System**
  - **Craniosacral**
    - Ocular Autonomics
      - Tectal autonomics — Neurons that arise from roots in mid-brain, pass to ciliary ganglia — terminate by forming synapses with motor neurons, whose axons proceed as ciliary nerves to the eyeballs.
    - Oro-anal Autonomics
      - Bulbar autonomics — Neurons arising from roots in medulla which emerge in 7th, 9th, 10th, and 11th cranial nerves.
      - Sacral autonomics — Neurons of the 2nd, 3rd, and 4th sacral spinal nerves send preganglionic fibers to pelvis — form nervus erigens, which proceeds to pelvic plexus.
  - **Thoracolumbar**
    - **Vertebral or Thoracolumbar**
      - Chain of ganglia which lie along ventrolateral aspects of vertebral column.
      - **Grouped as**
        - Cervical........... 3 prs.
        - Thoracic.......... 10–12 prs.
        - Lumbar........... 4 prs.
        - Sacral............. 4–5 prs.
      - **Connected**
        1. With each other by ganglia cords.
        2. With spinal nerves by rami communicantes.
        3. Distributed with spinal nerves to blood-vessels, glands, walls of viscera, and skin areas of body.
        4. Fibers from fifth to tenth or eleventh thoracic ganglia converge to form
           - Great splanchnic
           - Small splanchnic
    - **Three Great Plexuses**
      - Consists of masses of gray matter in thoracic and abdominal cavities.
      - Form
        - Cardiac plexus.
        - Celiac plexus.
        - Hypogastric plexus.
        - Connect with many others embedded in thoracic and abdominal viscera.
  - **Enteric**
    - Myenteric plexus — situated between the circular and longitudinal coats of digestive tube.
    - Submucous plexus — lies in the submucosa.
  - **Function** — Innervates (1) all plain muscular tissue, (2) the heart, and (3) the glands. Most important factor is reflex stimulation. Not under control of will. Influenced by emotions. Ganglia serves a relay stations.

- **Craniosacral and Thoracolumbar Systems**
  - Many of the viscera are supplied with nerves from both craniosacral and thoracolumbar systems — functions of these two sets are often antagonistic.
  - These two systems are interdependent, stimulation of one system or part of one system, likely to stimulate some part of the other system.
  - Thoracolumbar system is stimulated by intense excitement. Craniosacral system is not.
  - Nicotine paralyzes all autonomic ganglia. Most drugs affect either the craniosacral or the thoracolumbar, not both.

TABLE OF THE CRANIAL NERVES

Name	Nuclei of Origin and Termination	Distribution	Function
1. **Olfactory** (Sensory)	Central or deep processes of olfactory bulb	Nasal mucous membranes	Sense of smell.
2. **Optic** (Sensory)	Ganglionic cells of retina	Retina of eye	Sense of sight.
3. **Oculomotor** (Motor)	Nucleus in floor of cerebral aqueduct	Superior, inferior, and medial recti; inferior oblique, ciliaris, and sphincter pupillæ muscles	Motion.
4. **Trochlear** (Motor)	Nucleus in floor of cerebral aqueduct	Superior oblique of eye	Motion.
5. **Trigeminal** (Sensory and motor)	Fibers of *sensory* root arise from the semilunar ganglion which lies in cavity of dura mater near the apex of the petrous portion of the temporal bone. Fibers of the *motor* root arise from superior and inferior nuclei in pons.	(1) *Ophthalmic* distributes nerves to cornea, ciliary body, iris, lacrimal gland, conjunctiva, part of the mucous membrane of the nasal cavity, skin of the forehead, eyelid, eyebrow, and nose.	Sensation.
	Fibers from the *two roots coalesce* into one trunk and then subdivide into (1) the ophthalmic, (2) the maxillary, and (3) the mandibular.	(2) *Maxillary* distributes nerves to the dura mater, forehead, lower eyelid, lateral angle of orbit, upper lip, gums and teeth of upper jaw, mucous membrane and skin of cheek and nose.	Sensation.
		(3) *Mandibular* distributes branches to the temple, auricle of ear, lower lip, lower part of face, teeth and gums of mandible, and muscles of mastication.	Sensation and motion.
		Lingual nerve to mucous membrane of anterior part of tongue.	Sense of taste.

TABLE OF THE CRANIAL NERVES — *Continued*

NAME	NUCLEI OF ORIGIN AND TERMINATION	DISTRIBUTION	FUNCTION
6. **Abducent** (Motor)	Nucleus beneath floor of fourth ventricle	Medial rectus of one eye and lateral rectus of the other eye	Motion.
7. **Facial** (Sensory and motor)	*Sensory* fibers arise from the geniculate ganglion on the facial nerve.	Distributes nerves to the anterior two-thirds of the tongue (taste) and a few to the region of the middle ear.	Sensation.
	Motor fibers arise from a nucleus in the lower part of the pons.	Distributes nerves to the muscles of the face, part of the scalp, the auricle, and muscles of the neck.	Motion.
		Vasodilator fibers are distributed to the submaxillary and sublingual glands.	Secretion.
8. **Acoustic** (Sensory) Two sets of fibers	*Cochlear* from bipolar cells in the spiral ganglion of the cochlea	To the organ of Corti	Sense of hearing.
	Vestibular from bipolar cells situated in upper part of the outer end of the internal auditory meatus	To the semicircular canals	Equilibrium.
9. **Glossopharyngeal** (Sensory and motor)	*Sensory* fibers arise from the superior and petrous ganglia, situated on the trunk of the nerve, the former in the jugular foramen, the latter in the petrous portion of the temporal bone.	Distributes sensory nerves to mucous-membrane of fauces, tonsils, pharynx, and posterior third of tongue.	Sense of taste.
	Motor fibers arise from nucleus ambiguus, in the medulla.	Distributes motor fibers to the muscles of the pharynx, and secretory fibers to the parotid gland.	Motion. Secretion.

Name	Nuclei of Origin and Termination	Distribution	Function
10. **Vagus or pneumogastric** (Sensory and motor)	*Sensory* fibers arise from jugular ganglion and ganglion nodosum situated on trunk of nerve after it passes through the jugular foramen.	Distributes sensory nerves to the mucous membrane of the larynx, trachea, lungs, esophagus, stomach, intestines, and gall-bladder.	Sensation.
	Motor fibers arise from nucleus ambiguus in the medulla.	Distributes motor nerves to larynx, esophagus, stomach, small intestine, and part of the large intestine.	Motion.
		Distributes inhibitory fibers to heart.	
		Distributes secretory fibers to gastric and pancreatic glands.	Secretion.
11. **Accessory nerve or spinal accessory** (Consists of two parts, cranial and spinal) (Motor)	*Cranial* fibers arise from nucleus ambiguus in the medulla.	Distributes fibers to the pharyngeal and superior laryngeal branches of the vagus.	Motion.
	Spinal fibers arise from spinal cord as low as the fifth cervical nerve.	Distributes nerves to the sternocleidomastoid and trapezius muscles.	Motion.
12. **Hypoglossal**	Arises from the hypoglossal nucleus in the medulla.	Distributes nerves to the muscles of the tongue.	Motion.

CHAPTER X

EPITHELIAL TISSUE; MEMBRANES

Epithelial tissue is composed of cells held together by a small amount of cell cement or by special intercellular lymph with a surface boundary of cell cement. The cells are generally arranged so as to form a skin, or membrane, covering the external surfaces and lining the internal parts of the body; hence it is called a boundary tissue. It is devoid of blood-vessels, and is nourished by the absorption of lymph which passes to the cells by way of the minute spaces within the intercellular substance.

The varieties of epithelium may be classified in various ways. A very simple classification is as follows:

- **Epithelial tissue**
  - Squamous
    - Simple
      - Epithelium.
      - Endothelium.
    - Stratified.
  - Columnar.
  - Modified
    - Goblet.
    - Ciliated.
    - Neuro-epithelium.

Squamous epithelium. — This variety is called squamous because the cells on the free surface are flattened, scale-like, and fitted together to form a more or less regular mosaic.

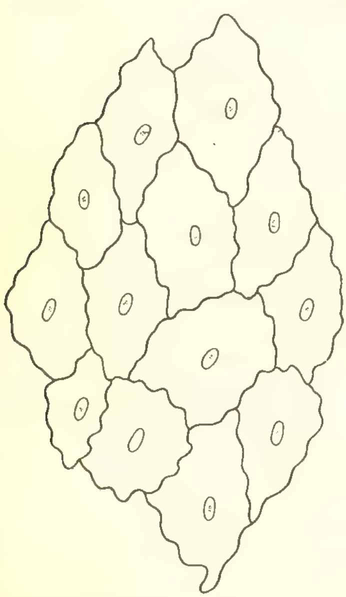


Fig. 124. — Simple Squamous Epithelium. Surface view.

Simple squamous epithelium consists of one layer of flat cells. It forms very smooth surfaces and secretes serum to lubricate them. It is found lining the alveoli of the lungs, in the crystalline lens of the eye, and in the membranous labyrinth of the inner ear. These tissues are derived from the ectoderm and entoderm and are called *epithelium.*

A tissue which is similar in structure and which is usually classified as epithelial is found lining the heart, blood, and lymph vessels. This tissue is derived from the mesoderm and is called *endothelium.*

Stratified squamous epithelium consists of several layers of cells which differ in shape. As a rule the cells of the deepest layer are columnar, the next round or many-sided (transitional), while those nearest the surface are always flattened and scale-like. The deeper soft cells of a stratified epithelium are separated from one another by a system of channels, which are bridged across by numerous fibers. They are continually multiplying by cell division, and as the new cells which are thus produced in the deeper parts increase in size, they compress and push outward those previously formed. In this way cells which were at first deeply seated are gradually shifted outward and upward, growing harder as they approach the surface. The older superficial cells are being continually rubbed off and new ones continually rise up to replace them.

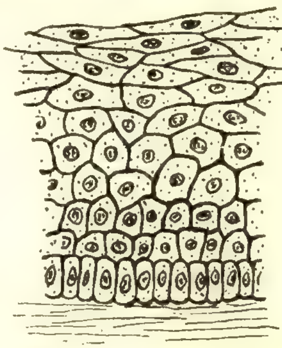


FIG. 125. — SECTION OF STRATIFIED SQUAMOUS EPITHELIUM. *A*, flattened cells near the surface; *B*, polygonal cells below these; *C*, lowermost columnar cells. (Schäfer.)

Function. — Wherever a surface is exposed to friction, we find stratified squamous epithelium performing its function of protection. It covers the body, forming the epidermis, and is found wherever the ectoderm folds in from the outside, *e.g.*, mouth, nose, and anus.

Columnar epithelium. — In this variety of epithelium the cells have a prismatic shape and are set upright on the surface which they cover. Epithelium consisting of only one layer of prismatic cells constitutes the *simple columnar* variety. Columnar epithelium is found in its most characteristic form lining the small intestine.

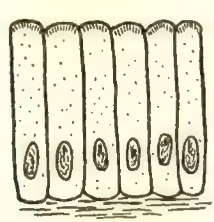


FIG. 126. — SIMPLE COLUMNAR EPITHELIUM FROM INTESTINAL MUCOSA.

Function. — The function of columnar epithelium is absorption and the secretion of digestive fluids.

Modified epithelium. — In order to meet particular work epithelial cells may undergo marked *modifications.* When these cells assume a peculiar chalice form, resulting from an accumulation of mucoid secretion, the cells are called *goblet* or glandular, and may be regarded as the simplest type of gland.

In some localities the free surface of columnar epithelium is provided with minute, hair-like processes, which are agitated incessantly with a lashing or vibrating motion. These minute and delicate processes are named *cilia* and are active prolongations of the cell protoplasm. The motion of an individual cilium may be compared to the lashlike motion of a short-handled whip, the cilium being rapidly bent in one direction. The motion does not involve the whole of the ciliated surface at the same moment, but is performed by the cilia in regular succession, giving rise to the appearance of a series of waves traveling along the surface like the waves tossed by the wind in a field of wheat. When they are in very rapid action, their motion conveys the idea of swiftly running water. As they all move in one direction, a current of much power is produced.

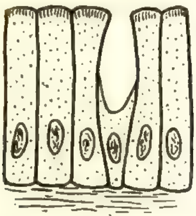


Fig. 127. — Goblet Cell from Epithelium Lining Large Intestine.

Function. — The function of cilia is motion.

In man their use is (*a*) to impel secreted fluids, or other matters, along the surfaces from which they extend, and (*b*) to prevent the entrance of foreign matter into cavities.

Ciliated epithelium is found in the respiratory tract from the nose to the end of the bronchial tubes (with the exception of the pharynx and vocal cords); in the uterine tubes and the upper part of the uterus in the female, and in the efferent ducts of the testes in the male.

Epithelium which contains the end-organs of nerves is described as *neuro-epithelium*, or *sensory*. For example, in the epithelium lining the nose two kinds of cells develop, olfactory and supporting cells. The olfactory cells send their axons into the brain, where they come into relation with other neurons in the olfactory tract. The olfactory epithelium is thus a neuro-epithelium, its sensory cells are nerve cells. They are derived from the ectoderm. The cells of the organ of Corti, the taste buds, and the retina are other examples of neuro-epithelium.

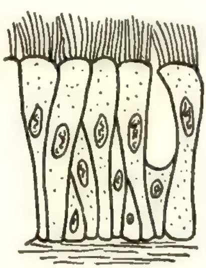


Fig. 128. — Ciliated Epithelial Cells from the Human Trachea. (Highly magnified.)

Function. — The function of the sensory cells is sensation, and the term, supporting, describes the function of the others.

MEMBRANE

The word *membrane* in its widest sense is used to designate any thin expansion of tissues. In a restricted, although the commonest sense, the word *membrane* is used to denote an enveloping or a lining layer made up of tissues.

Classification of membranes. — The chief membranes of the body are classified as (1) serous, (2) synovial, (3) mucous, (4) cutaneous.

Serous membranes. — Serous membranes are thin, transparent, strong, and elastic. The surfaces are moistened by a fluid called serum. They consist of simple squamous epithelium and a layer of connective tissue, which serves as a base. They are derived from the mesoderm. Since the epithelium is derived from mesoderm it is called *mesothelium.*

Serous membranes are attached to the underlying parts by areolar connective tissue, called *subserous* tissue. They are found:

(1) Lining the body cavities and covering the organs which lie in them.

(2) Lining the vascular system.

(3) Forming the fascia bulbi and part of the membranous labyrinth of the ear.

(1) *Lining the body cavities and covering the organs which lie in them.* — With one exception, these membranes form closed sacs, one part of which is attached to the walls of the cavity which it lines, — the *parietal* portion, — whilst the other is reflected over the surface of the organ or organs contained in the cavity, and is named the *visceral* portion of the membrane. In this way the viscera are not contained within the sac, but are really placed outside of it, and some of the organs may receive a complete, while others receive only a partial, or scanty, investment.

The inner surface of a serous membrane is free, smooth, and lubricated; in this group the inner surface of one part is applied to the corresponding inner surface of some other part, only a small quantity of fluid being interposed between the surfaces. The organs situated in a cavity lined by a serous membrane, being themselves also covered by it, can thus glide easily against its walls or upon each other, their motions being rendered smoother by the lubricating fluid.

This class of serous membranes includes:

(*a*) *The two pleuræ,* which cover the lungs and line the chest. (See Fig. 206.)

(*b*) *The pericardium,* which covers the heart and lines the outer fibrous pericardium. (See Fig. 141.)

(*c*) *The peritoneum,*[1] which lines the abdominal cavity, clothes its contained viscera, and also the upper surface of some of the pelvic viscera. (See Fig. 199.)

(2) *Lining the vascular system.* — This is the internal coat of the heart, blood-vessels, and lymphatics.

(3) *Forming the fascia bulbi and part of the membranous labyrinth of the ear.*

(*a*) Between the pad of fat in the back of the orbit and the eyeball is a serous sac — the fascia bulbi — which envelops the eyeball from the optic nerve to the cilary region and separates the eyeball from the bed of fat on which it rests.

(*b*) The membranous labyrinth of the ear has somewhat the same general form as the bony cavities in which it is contained.

Function. — The most important function of serous membrane is protection, which is accomplished in two ways: (1) by forming a smooth, slippery lining or covering for the blood-vessels, cavities, and viscera with which it is associated, and (2) by secreting serum which acts as a lubricating fluid and tends to lessen friction.

Synovial membranes. — Serous membranes which are associated with the bones and muscles are called synovial membranes. Synovial membranes secrete *synovia,* a viscid, glairy fluid that resembles the white of egg.

They are divided into three classes, *viz.:* (1) articular, (2) mucous sheaths, and (3) bursæ mucosæ.

(1) *Articular synovial membranes* line the articular capsules of the freely movable joints. (See Fig. 71.)

(2) *Mucous sheaths* are elongated closed sacs which form sheaths for the tendons of some of the muscles, particularly the flexor and the extensor muscles of the fingers and toes. They facilitate the gliding of the tendons in the fibro-osseous canals.

(3) *Bursæ mucosæ,* or synovial bursæ, are simple sacs, interposed, to prevent friction, between two surfaces which move upon each other. They may be subcutaneous, submuscular, subfascial, and subtendinous. The large bursa, situated over the patella,[2] is an example of a subcutaneous bursa. Similar, though smaller,

[1] The peritoneal cavity in the female is an exception to the rule that serous membranes form perfectly closed sacs, as it has two openings by which the uterine (*Fallopian*) tubes communicate with its cavity.

[2] Inflammation of the bursa over the patella is called house-maid's knee.

bursæ are found over the olecranon, the malleoli, the knuckles, and other prominent parts.

Function. — The function of synovial membranes is the same as that of serous membranes. Both serous and synovial membranes are derived from the mesoderm.

Mucous membranes. — The mucous membranes of different parts are continuous, and they may be reduced to two great divisions; namely, (1) gastropulmonary, and (2) the genito-urinary.

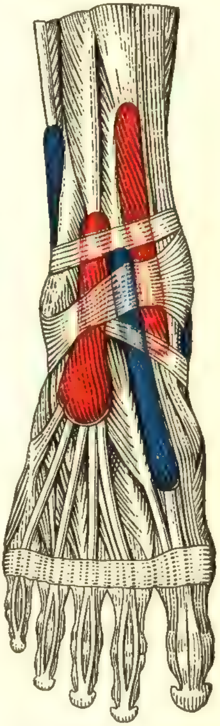


FIG. 129. — THE ANTERIOR ANNULAR LIGAMENT OF THE ANKLE AND THE SYNOVIAL MEMBRANES OF THE TENDONS BENEATH IT. Artificially distended. (Gerrish.)

(1) The *gastropulmonary* mucous membrane lines the inside of the alimentary canal, the air passages, and the cavities communicating with them. It commences at the edges of the lips and nostrils, proceeds through mouth and nose to the throat, and thence is continued throughout the entire length of the alimentary canal to the anus. At its origin and termination it is continuous with the external skin. It also extends throughout the trachea, bronchial tubes, and air sacs. From the interior of the nose the membrane is prolonged into the frontal, ethmoidal, sphenoidal, and maxillary sinuses, also into the lacrimal passages, and under the name of conjunctival membrane, over the fore part of the eyeball and inside of the eyelids, on the edges of which it again meets with the skin. From the upper and back part of the pharynx a prolongation extends on each side, along the passage to the ear — the auditory (Eustachian) tube[3] — and offsets in the alimentary canal go to line the salivary, pancreatic, and biliary ducts, and the gall-bladder.

(2) *Genito-urinary.* — The genito-urinary mucous membrane lines the inside of the bladder, and the whole urinary tract from the interior of the kidneys to the orifice of the urethra; it lines the ducts of the testes, epididymis, and seminal vesicles; it also lines the vagina, uterus, and uterine (Fallopian)[4] tubes. A study of Figs. 131 and 132 will make this plain.

[3] Bartolommeo Eustachio, Italian anatomist, 1520–1574.
[4] Gabriel Fallopius, Italian anatomist, 1523–1562.

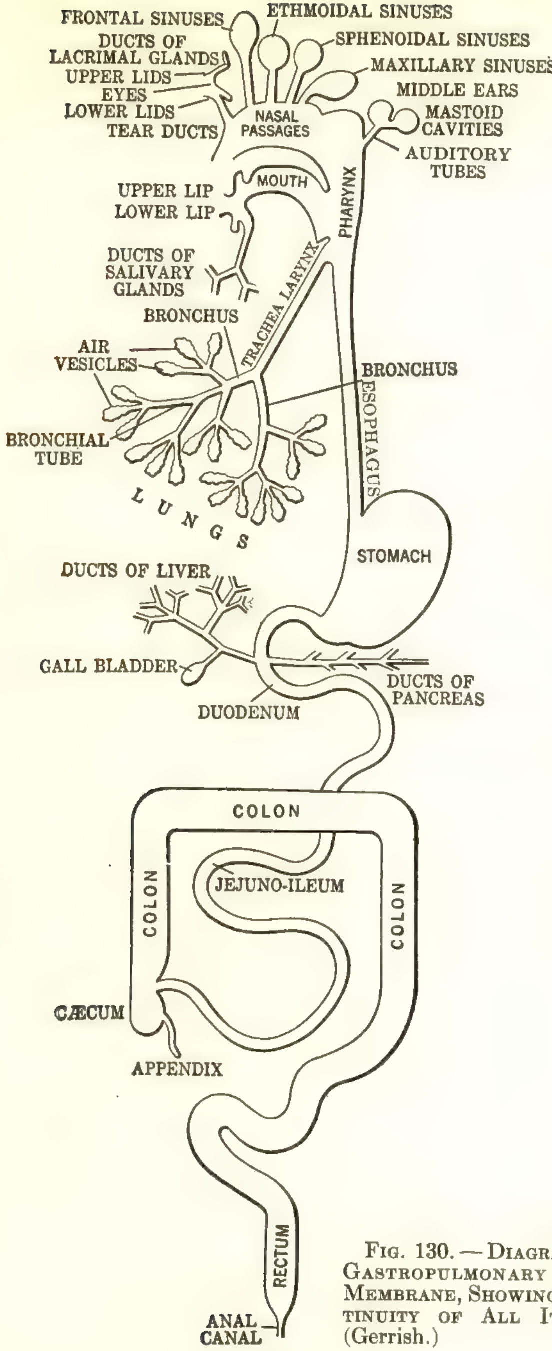


Fig. 130. — Diagram of the Gastropulmonary Mucous Membrane, Showing the Continuity of All Its Parts. (Gerrish.)

Structure. — A mucous membrane is usually composed of four layers of tissue: (1) epithelium, (2) basement membrane, (3) corium, and (4) muscularis mucosæ.

(1) *Epithelium* is the surface layer. It may be stratified squamous, as in the throat; columnar, as in the stomach and intestine; or ciliated, as in the respiratory tract.

(2) The *basement membrane* consists of a layer of flattened cells and is really part of the corium.

(3) The *corium* is composed of either areolar or lymphoid connective tissue and contains blood-vessels.

(4) The *muscularis mucosæ* consists of a thin layer of muscular tissue, which is not always present, *e.g.*, trachea.

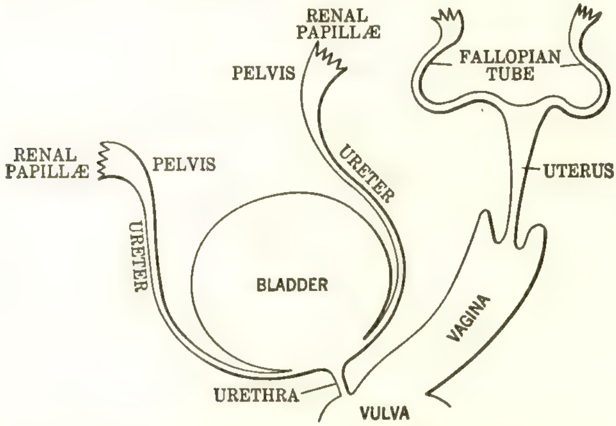


FIG. 131. — DIAGRAM OF THE FEMALE GENITO-URINARY MUCOUS MEMBRANE, SHOWING CONTINUITY OF ALL ITS PARTS. (Gerrish.)

The mucous membranes are attached to the parts beneath them by areolar connective tissue, here named *submucous.* This differs greatly in quantity as well as in consistency in different parts. The connection is in some cases close and firm, as in the cavity of the nose. In other instances, especially in cavities subject to frequent variations in capacity, like the esophagus and the stomach, it is lax; and when the cavity is narrowed by contraction of its outer coats, the mucous membrane is thrown into folds, or *rugæ,* which disappear again when the cavity is distended. In certain parts the mucous membrane forms permanent folds that cannot be effaced, and these project conspicuously into the cavity which it lines. The best-marked example of these folds is seen in the small intestine, where they are called *circular folds* (valvulæ conniventes), which increase the area of absorbing surface for the products of digestion.

In some locations the free surface of mucous membrane contains minute glands, or is covered with papillæ or villi.

Function of mucous membranes. — The function of mucous membranes is (1) protection, (2) support of blood-vessels and lymphatics, (3) to furnish a large amount of surface for secretion and absorption.

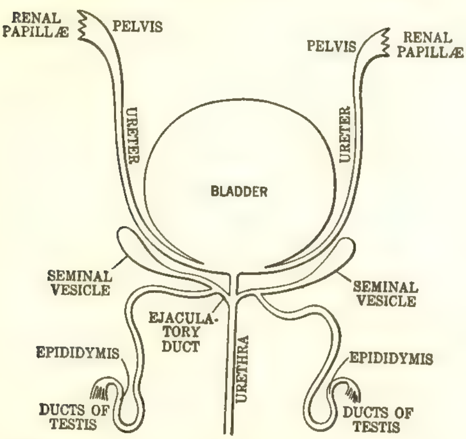


FIG. 132. — DIAGRAM OF THE MALE GENITO-URINARY MUCOUS MEMBRANE, SHOWING CONTINUITY OF ALL ITS PARTS. (Gerrish.)

(1) It protects by forming a lining or inside skin for all the passages that communicate with the exterior. These passages are subject to the contact of foreign substances, which are introduced into the body; and waste materials, which are expelled from the body. The mucus which it secretes is a thicker and more sticky fluid than either serum or synovia, and by coating the surface lessens the possibility of irritation from food, waste materials, or secreted substances. The cilia of the respiratory tract also assist in the function of protection. They keep up an incessant motion, and thus carry mucus toward the outlet of these passages. Dust and foreign materials usually become entangled in the mucus and are forced out with it.

(2) The redness of mucous membranes is due to their abundant supply of blood. The small blood-vessels which convey blood to the mucous membranes divide in the submucous tissue, and send smaller branches into the corium, where they form a network of capillaries just under the basement membrane. The lymphatics also form networks in the corium, and communicate with larger vessels in the submucous tissue below.

(3) The projections of mucous membrane, such as the circular folds (see Figs. 216 and 217) and villi, increase the surface for absorption, and enable the membrane to carry more blood-vessels and lymphatics.

Cutaneous membrane. — By this term is indicated the membrane which covers the body and is commonly spoken of as skin. It is a complex structure, and has several functions in addition to serving as a protective covering for the deeper tissues lying beneath it. It will be more fully considered in Chapter XXII.

SUMMARY

Epithelial — Tissues of cells and little intercellular substance. Boundary tissue.

- **Classification of Epithelial Tissues**
  - Squamous
    - Simple — one layer of flat cells
      - Endothelium — derived from mesoderm.
      - Epithelium — derived from ectoderm.
    - Stratified — several layers of cells.
  - Columnar — cells set upright on surface.
  - Modified
    - Goblet — chalice shape.
    - Ciliated — microscopic, hair-like processes at free surface.
    - Neuro-epithelium contains end-organs of nerves.
- **Function**
  1. *Protection.* — Some varieties are specially modified so as to form protective membranes. Example — skin.
  2. *Motion.* — This is seen in the cilia.
  3. *Absorption.* — This is particularly well seen in the digestive tube.
  4. *Secretion.* — Every secreting organ must contain epithelial cells. Mucous and serous membranes are examples of secreting organs.
  5. *Special sensation.* — The organs of the special senses contain epithelial cells. Examples — eyes, ear, nose, etc.
- **Membranes**
  - **Definition** — Any thin expansion of tissues that serves as a lining or covering.
  - **Varieties**
    1. Serous membranes.
    2. Synovial membranes.
    3. Mucous membranes.
    4. Cutaneous membranes.

SEROUS MEMBRANES

- **Consist of**
  1. Simple squamous epithelium.
  2. A thin layer of connective tissue.
- **Derived** — From the mesoderm and called mesothelium.
- **Found** — Lining closed cavities or passages that do *not* communicate with the exterior. They are moistened by *serum.*
- **Three Classes**
  - Lining the body cavities and covering the organs which lie in them
    - Pleuræ — cover the lungs and line the chest.
    - Pericardium — covers the heart and lines the outer fibrous pericardium.
    - Peritoneum — covers the abdominal and the top of some of the pelvic organs, lines the abdominal cavity.
  - Lining the vascular system.
    - Heart.
    - Blood-vessels.
    - Lymphatics.
  - Forming the fascia bulbi and part of the membranous labyrinth of the ear.
- **Function** — Protection
  1. Furnishes a cover or lining
     - Viscera.
     - Vascular system.
     - Certain cavities.
  2. Furnishes a secretion — serum — which acts as a lubricant.

SYNOVIAL MEMBRANES

- Consist of thin serous tissue associated with bones and muscles.
- **Three Classes**
  - Articular synovial membranes — Surround cavities of movable joints.
  - Mucous sheaths — Form sheaths for tendons.
  - Bursæ mucosæ — Sacs interposed between two surfaces which move upon each other.
- **Function**
  - Furnishes a lining or cover
    - Joints.
    - Tendons.
    - Sacs under skin, muscles, and tendons.
  - Furnishes a secretion — synovia — which acts as a lubricant.

MUCOUS MEMBRANES

- **Found** — Lining passages that communicate with the exterior and are protected by *mucus*.
- **Two Divisions**
  - Gastropulmonary
    - Alimentary canal.
    - Air-passages.
    - Cavities communicating with both alimentary canal and air-passages.
  - Genito-urinary
    - Urinary tract.
    - Generative organs.
- **Consist of**
  1. Epithelium
     - Stratified.
     - Columnar.
     - Ciliated.
  2. Basement membrane, a layer of flat cells.
  3. Corium
     - Areolar, or
     - Lymphoid tissue, which contains blood-vessels.
  4. Muscularis mucosæ — thin layer of muscular tissue which is not always present.
- **Projections**
  - Rugæ — temporary folds
    - Esophagus.
    - Stomach.
  - Circular folds — permanent folds of mucous membrane found in small intestine.
  - Papillæ — conical processes of mucous membrane best seen on tongue. Contain blood-vessels and nerves.
  - Villi — tiny thread-like projections of the mucous membrane of small intestine.
- **Function**
  - Protection
    - Inside skin.
    - Secretion of mucus.
    - Action of cilia.
  - Support — for network of blood-vessels.
  - Absorption and Secretion — Various modifications increase the surface.

CHAPTER XI

THE BLOOD

The body consists of an enormous number of cells, and each cell is supplied with materials to enable it to carry on its activities, and at the same time the waste materials, that are the result of its activities, are removed. Many cells are far from the source of supplies and the organs of elimination; hence the need of a medium to distribute supplies and collect waste. This need is met by the liquid tissues — blood and lymph — which consist of cells and an intercellular liquid.

THE BLOOD

Characteristics. — The most striking external feature of the blood is its well-known ~~color, which is bright red~~, approaching to scarlet in the arteries, but of a dark red or crimson tint in the veins. It is a somewhat sticky liquid, a little heavier than water; its specific gravity varies between 1.041 and 1.067.[1] It has a peculiar odor, a saltish taste, a temperature of about 38.5° C. (100° F.) and a reaction that is slightly alkaline (varies in pH from 7.38 to 7.4).[2]

Quantity of blood. — The quantity of blood contained in the body of an adult is estimated to be about $\frac{1}{20}$ of the body weight.[3] This, in an individual weighing 70 K. (154 lbs.), would weigh about 3.5 K. (7.7 lbs.), or measure 3.3 liters (4 qts.).

In health there is little variation in quantity, but in pathological conditions changes may occur. Plethora or an increase in volume may occur in polycythemia, chlorosis, and sometimes anemia.

[1] The specific gravity of any liquid is the weight of the liquid (blood, urine, etc.) compared with the weight of an equal volume of distilled water at 15° C. (60° F.), the weight of the water being considered 1.000.

[2] An alkaline solution is one in which the hydroxyl ions (OH) are in excess. An acid solution is one in which the hydrogen ions (H) are in excess. A neutral solution is one in which the hydroxyl and hydrogen ions are in equal concentration. In physiology the concentration of hydrogen ions is expressed for convenience' sake as the hydrogen exponent (symbol pH). The potentiometer is an instrument for measuring the relative concentration of hydrogen and hydroxyl ions. On it substances having a pH of 7 are neutral, above, from 7 to 14, are increasingly alkaline, and below, from 7 to 1, are increasingly acid.

[3] The figures reported by different observers vary considerably, possibly because different methods are employed in determining them. Haldane and Smith give $\frac{1}{20}$ body weight.

Composition of blood. — Seen with the naked eye, the blood appears opaque and homogeneous; ~~but~~ when examined with a microscope, it is seen to consist of minute ~~particles called *cells*~~ or ~~corpuscles~~ floating in an intercellular liquid which is called *plasma.*

- **Blood**
  - Cells
    - Erythrocytes or red cells.
    - Leucocytes
      - Lymphocytes.
      - Monocytes.
      - Granular leucocytes.
    - Thrombocytes or blood platelets.
  - Plasma — intercellular liquid.

Red Cells. — Under the microscope red cells are seen to be circular discs, without nuclei and biconcave in profile. The average

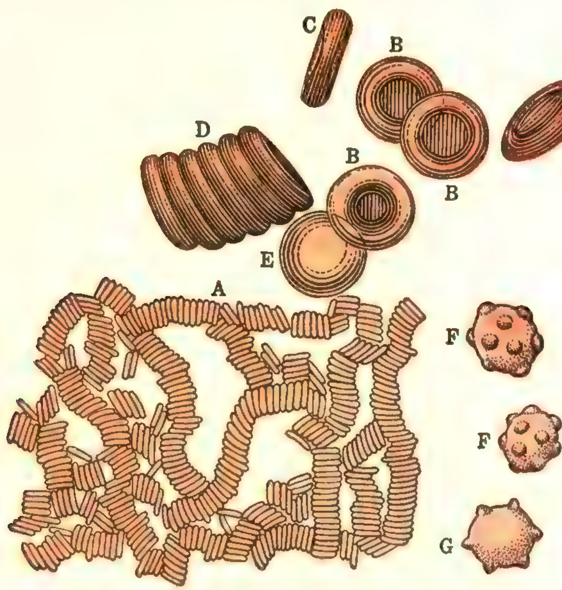


FIG. 133. — RED CELLS OF THE BLOOD, MAGNIFIED.

A — Moderately magnified. The red cells are seen lying in rouleaux.
B — Red cells much more highly magnified, face view; *C*, in profile; *D*, in rouleaux, more highly magnified; *E*, a red cell swollen into a sphere by imbibition of water.
F — Red cells puckered or crenated all over.
G — Same at edge only.

size is about 7.7 μ[4] (0.0077 mm.) in diameter. The area of an average cell is 0.000128 sq. mm. When viewed singly, they do not appear red, but merely of a yellowish red tinge or yellowish green in

[4] The micron (symbol μ) equals one-thousandth of a millimeter (0.001 mm.). For various units of measurement in micrometry see *The Microscope* by Simon Gage.

venous blood. It is only when great numbers of them are gathered together that a distinctly red color is produced.

Red cells consist of a colorless, filmy, elastic framework or stroma, in which hemoglobin is deposited. They have no nuclei, are soft, flexible, and elastic, so that they readily squeeze through apertures and passages narrower than their own diameters, and immediately resume their proper shape.

Hemoglobin is a conjugated protein consisting of a protein named globin and a non-protein pigment portion named hematin, which contains iron. The proportion of iron in hemoglobin is about .33 per cent. In the presence of oxygen hemoglobin has the power to combine with it to form an unstable compound called oxyhemoglobin, and in a plasma environment where oxygen is scarce, it gives up this oxygen, and is then known as reduced hemoglobin.

Function of the red cells. — The red cells, or erythrocytes, are *oxygen carriers.* This chief function is dependent upon the presence of hemoglobin. Exposed to the air in the lungs the hemoglobin becomes fully charged with oxygen and is known as oxyhemoglobin. The red cells carry this oxyhemoglobin to the cells of the tissues, where it gives up the loosely engaged oxygen. It is then known as reduced hemoglobin and is ready to be carried to the lungs for a fresh supply. The color of the blood is dependent upon the combination of the hemoglobin with oxygen; when the hemoglobin has its full complement of oxygen, the blood has a bright red hue; when the amount is decreased, it changes to a dark crimson hue. The scarlet blood is usually found in the arteries, and is called arterial; the dark crimson in the veins, and is called venous blood.

Hemolysis or Laking. — The loss of hemoglobin from the red cells and its solution in the plasma is called hemolysis. Substances that cause this action are called hemolytic agents. Hemolysis may be brought about (1) by free dilution with water, which diminishes the concentration and the osmotic pressure of the plasma, (2) by adding ether or chloroform, (3) by adding salts or fatty acids, (4) by adding bile salts, (5) alternate freezing and thawing, (6) the action of foreign blood serums,[5] and (7) by such agents as snake venom, the products of defective metabolism, the products of bacterial activity or immunizing substances produced

[5] Before transfusing blood from one human being to another, the blood of the donor is always tested in several ways. The purpose of one test is to make sure that it will not hemolyze the red cells of the recipient.

within the body. Red cells which have lost their hemoglobin are colorless and incapable of serving as oxygen carriers.

Number of red cells. — The average number of red cells in a cubic millimeter of healthy blood is given as 5,000,000 for men

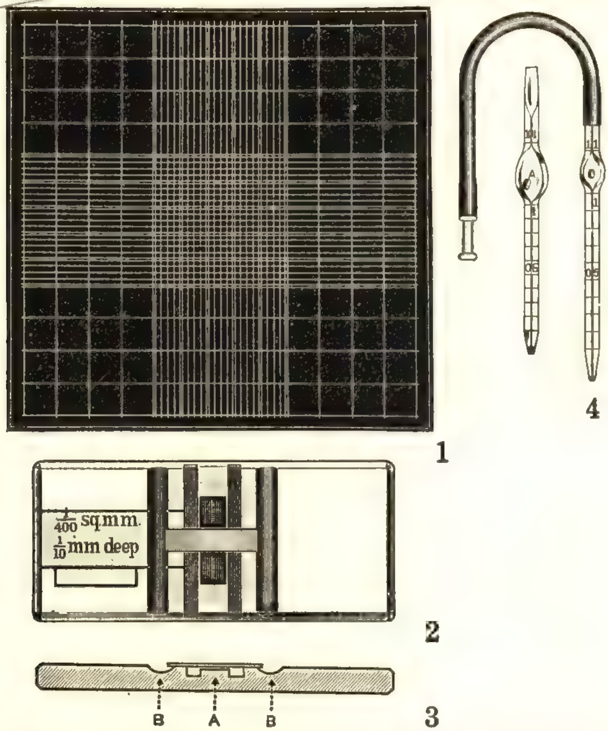


Fig. 134. — An Hemocytometer, Consisting of a Counting Chamber and Pipettes for Making Counts of Blood Cells. 1, counting chamber; 2, counting slide showing two counting chambers; 3, edge view of counting slide; 4, Thoma diluting pipettes. *A*, counting chamber, *i.e.*, space between slide and cover glass — 0.1 mm. in depth; *B*, groove ensuring resting of cover glass on cover glass rests. The pipette with 101 above the bulb is for diluting blood for red cell counts, the pipette with 11 above the bulb is for diluting blood for white cell counts. (Modified from *Practical Bacteriology, Blood Work and Animal Parasitology.* E. R. Stitt. Courtesy of P. Blakiston's Son & Co. and A. H. Thomas Company.)

and 4,500,000 for women. This would give about 20,000,000,000,000 as the total number in the blood in the body. Since the area of one cell is approximately 0.000128 sq. mm., the area of the total number of cells would be about 3200 sq. meters. Pathological conditions may cause a marked diminution in number, and differences have been observed even in health. The number varies with altitude, temperature, the constitution, nutrition,

and manner of life; with age, being greatest in the fetus and newborn child; with the time of day, showing a diminution after meals; in the female, menstruation is accompanied by an increase and pregnancy by a decrease.

The instrument used for counting the number of blood cells is called an hemocytometer. This consists of a counting slide and diluting pipettes for counting red and white cells. If the red cell pipette is filled to the 0.5 mark with blood and then to the 101 mark with physiological saline, Hayem's solution, etc., the bulb will contain a 1 : 200 dilution of blood.

The slide is ruled in both directions by parallel lines $\frac{1}{20}$ mm. apart, and the cover glass is held $\frac{1}{10}$ of a mm. above the slide. If a drop of the solution from the bulb of the pipette for counting red cells is mounted on the slide and covered, examination through the microscope will show over the area bounded by four of these lines, $\frac{1}{20}$ of a mm. apart, $\frac{1}{4000}$ of a cu. mm. of solution, $\frac{1}{200}$ of which is blood. The cells seen will be those contained in $\frac{1}{800000}$ of a cu. mm. of blood. If the cells in 80 of these squares are counted and this figure multiplied by 10,000, it will give the number of red cells in one cu. mm. of blood; *e. g.*, if one sees 450 cells in 80 squares and multiplies this by 10,000, it will give 4,500,000. Exact technique is necessary in making blood-cell counts. For this technique reference should be made to textbooks of clinical diagnosis.

Polycythemia. — The condition in which there is an increase of red cells above the normal is called polycythemia.[6] Conditions associated with cyanosis and residence in high altitudes are usually followed by polycythemia. Due to the low atmospheric pressure existing in high altitudes it is thought that the ability of the hemoglobin to combine with oxygen is lessened, and this reduction of oxygen tends to stimulate the formation of new cells. This result represents the chief benefit anemic people derive from residence in high altitudes.

Anemia. — This term is applied to conditions associated with a deficiency of red cells, or a deficiency of hemoglobin in the cells. A deficiency of red cells results from: (1) hemorrhage, (2) hemolysis, (3) inability to produce new red cells due to lack of nutritious food, diseases of the bone-marrow, and various infections. When severe anemia occurs during the adolescent period of girls, it is called *chlorosis.* It is not as common as formerly, probably because the modern girl leads a healthier out-door life.

Sufferers from anemia are greatly benefited by a diet rich in iron. The visceral meats, such as beef liver, heart, and brain, are rich sources of iron. Certain vegetables, such as spinach, lentils, peas, beans, and cereals such as graham flour, oatmeal, and shredded wheat, contain a high percentage of iron.

[6] In cases of severe watery diarrhea causing marked loss of water from the blood, the number of red cells per cubic millimeter is increased, but the total number in the body is not.

The *percentage of hemoglobin* can be obtained by comparing the color of blood with standard color comparators. Normal blood is considered 100 per cent. The number of erythrocytes is obtained by microscopic examination, and the normal number is considered 100 per cent. From these the *color index* can be derived as follows: use the percentage of hemoglobin as the numerator and the percentage of red cells as the denominator of a fraction, *e.g.*, $\frac{100}{100}$. If the number of cells is normal, it is reckoned as 100 per cent, and if the hemoglobin is reduced to 70 per cent, this gives us $\frac{70}{100}$ or $\frac{7}{10}$ and shows that the cells contain only $\frac{7}{10}$ of their normal amount of hemoglobin.

Life cycle of red cells. — The length of the life of a red cell in the circulation is not definitely known. It has been thought that the red cells are formed from nucleated cells called erythroblasts, which are colorless. During the process of multiplication the cytoplasm gradually shows the presence of hemoglobin and the erythroblast becomes a nucleated red cell. At a later stage of development the nucleus is expelled, leaving a fully formed red cell. Following hemorrhage and in certain pathological conditions, the process of blood formation is stimulated, and red cells containing nuclei are forced out prematurely and are found in the circulation. Recent experiments indicate that red cells originate directly from the endothelial cells of the blood capillaries, which means that the erythroblast is an endothelial cell. It has been demonstrated that in the adult, red cells are produced in the red marrow of bones. In the embryo red cells are formed in the liver and spleen, as well as in the red marrow. Just when and how the red cells disintegrate is not known. One supposition is that as they become aged they undergo hemolysis in the blood stream. Another is that they are destroyed in the spleen, lymph-nodes, and liver.

White cells. — The white cells are minute masses of nucleated protoplasm. They are variable in size, some smaller than the red corpuscles, but in human blood the majority are larger. They are gray (not white) in color.

Number of white cells. — The number of white cells in a cubic millimeter of healthy blood is from 5000 to 7000, a ~~proportion~~ of about one white to 700 red. An increase in number is designated as *leucocytosis*, and occurs in such infections as pneumonia, appendicitis, or an abscess in the body. A decrease in the number of leucocytes is designated as *leucopenia*.[7] It is a characteristic symptom of typhoid fever and tuberculosis. Physiological leuco-

[7] This should not be confused with *leukemia*, a disease characterized by an increase in the white cells of the blood. Normal *temporary* increases to 20,000 or more after exercise, etc. are thought to be due to shifts in circulation.

cytosis up to 9000 occurs under normal conditions, such as digestion, exercise, cold baths, pregnancy, etc. 10,000 or more per cu. mm. is usually considered pathological leucocytosis.

If the white cell pipette, Fig. 134, is filled to the 0.5 mark with blood and then to the 11 mark with $1\frac{1}{2}$ per cent acetic acid solution, Toisson's solution, etc., the bulb will contain a 1 : 20 dilution of

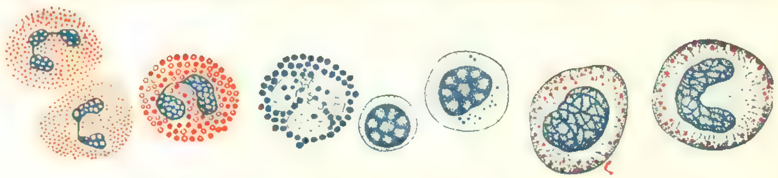


FIG. 135. — WHITE CELLS OF THE BLOOD AS SEEN WHEN STAINED WITH WRIGHT'S BLOOD STAIN. (Modified from *Practical Bacteriology, Blood Work and Animal Parasitology*. E. R. Stitt. Courtesy of P. Blakiston's Son & Co.)

blood. If a drop of the solution from the bulb of the pipette is mounted on the slide and covered, examination through the microscope will show over the area of one of the large corner squares, each of which has an area of one square mm., $\frac{1}{10}$ of a cu. mm. of solution, $\frac{1}{20}$ of which is blood. The cells seen will be those contained in $\frac{1}{200}$ of a cu. mm. of blood. If the cells in four of these large squares are counted and multiplied by 50, it will give the number of white cells in one cu. mm. of blood; *e.g.*, if one sees 140 cells in four large squares and multiplies this by 50, it will give 7000.

Ameboid movement. — Leucocytes possess the power of making ameboid movements, which has earned for them the name of "wandering" cells. This power enables them to migrate through the walls of the capillaries into the surrounding tissues. This process is called migration and occurs normally, but is greatly stimulated and increased by pathological conditions.

Varieties of white cells. — The white cells have been classified in various ways, depending upon differences in structure, the presence or absence of granules, and the reactions of the granules, when present, to different dyes. They are usually divided into three principal groups and these again into several others, as follows:

1. **Lymphocytes**	(*a*) **Small.** (*b*) **Large.**
2. **Monocytes**	(*a*) **Large mononuclear.** (*b*) **Transitional.**
3. **Granular leucocytes**	(*a*) **Polymorphonuclear or neutrophiles.** (*b*) **Eosinophiles or acidophiles.** (*c*) **Mast-cells or basophiles.**

Lymphocytes arise from the reticular tissue of the lymph-nodes of the body. Their cytoplasm is non-granular.

(*a*) *Small lymphocytes* are about the size of a red cell. They have a large round nucleus surrounded by a rim of clear protoplasm. They form from 20 to 25 per cent of the total.

(*b*) *Large lymphocytes* are larger than the first mentioned and have a greater amount of cytoplasm, but are fewer in number.

Monocytes include the large mononuclear and transitional leucocytes. They are large leucocytes with a single nucleus, and they can act as phagocytes. They form about 5% of the total number of leucocytes.

Granular leucocytes [8] show marked ameboid movement.

(*a*) *Polymorphonuclear leucocytes or neutrophiles* have a nucleus that is lobulated, and the granules of the cytoplasm stain with neutral dyes. They form from 60 to 75 per cent of the total number of leucocytes. They ingest bacteria (*phagocytosis*) and in the adult are formed in the marrow tissue.

(*b*) *Eosinophilic leucocytes or acidophiles* are similar in size and structure to the polymorphonuclear forms, but the granules of the cytoplasm are larger and stain with acid dyes such as eosin. Normally they are present in small numbers (2%), but under certain pathological conditions they show a marked increase. It is thought they arise in the bone marrow, like the polymorphonuclears.

(*c*) *Mast cells or basophilic leucocytes* have a polymorphic nucleus, and the granules of the cytoplasm stain with basic dyes. They are found in small numbers ($\frac{1}{2}$%). Nothing is known in regard to their function.

The proportion of the different classes of leucocytes in the blood has been found to vary during diseased conditions, especially during infections, and has come to have a practical value in diagnosis of disease by blood examination.

Functions of the white cells. — The functions of the white blood cells are supposed to be different for different forms. Important functions are: (1) they help to protect the body from pathogenic bacteria, and other foreign organisms. It is assumed that they either ingest bacteria and thus destroy them directly, or that they form certain substances called *bacteriolysins*, which have the power of dissolving them. Leucocytes which ingest bacteria are called *phagocytes*, and the process is called *phagocytosis*. This theory is known as the "phagocytosis theory of Metchnikoff." [9] The poly-

[8] They are also called *granulocytes*, in some texts.
[9] Elie Metchnikoff, Russian bacteriologist, 1845–1916.

morphonuclear leucocytes are thought to be most active in attacking bacteria, and Metchnikoff called them *microphages*. According to some authorities phagocytosis is dependent upon certain substances called *opsonins*,[10] which are found in the blood and which prepare the bacteria for ingestion by the leucocytes. (2) They coöperate in ~~promoting~~ tissue repair and regeneration. It is thought that the cells of connective and epithelial tissue cannot obtain material for growth directly from the blood. On the contrary, the leucocytes can manufacture or synthesize growth-promoting substances directly from the blood. It is proposed to call these substances *trephones*. (3) They aid in absorption from the intestines. (4) They take part ~~in the clotting of blood. (5) They~~ help to maintain the normal ~~supply of blood-proteins~~ ~~found~~ in the ~~plasma.~~ The blood-proteins are not those found in digested food, and it may be that the leucocytes act as unicellular glands forming the typical blood-proteins, and as a result of their metabolism aid in keeping up the normal supply of blood proteins.

Inflammation. — When any of the tissues become inflamed either as the result of injury or infection, the first effect is irritation, followed by an increased supply of blood to the part. If the irritation continues or is severe, the flow of blood begins to slacken, and a condition of stasis or engorgement results. The leucocytes become particularly active and migrate through the walls of the blood-vessels into the infected tissues in large numbers. Some of the blood-plasma exudes, and a small number of red cells are forced through the capillary walls. This general condition is described as inflammation, and the symptoms of pain, heat, redness, swelling, and loss of function are due: (1) to irritation caused by the toxins of the bacteria, (2) to the increased supply of blood, (3) to the engorgement of the blood-vessels, and (4) to the collection of fluid in the tissues, which is spoken of as inflammatory exudate. Under these conditions a death struggle between the leucocytes and bacteria takes place. If the leucocytes are victorious, they not only kill the bacteria but remove every vestige of the struggle, and find their way back to the blood. This process of recovery is described as resolution, and is dependent upon the individual's resistance, *i.e.*, the rapid formation of phagocytes, opsonins, etc.

If the bacteria are victorious, large numbers of phagocytes and tissue cells will be destroyed and suppuration, *i.e.*, the formation of pus, ensues. Pus consists of dead and living bacteria, phagocytes, disintegrated tissue cells, and material that has exuded from the blood-vessels.

Also, in the case of a wound, the leucocytes, by virtue of their ameboid movements, escape from the blood-vessels, accumulate in the region of the wound, and act as barriers against infection. When inflammation is so deeply seated that the local symptoms cannot be observed, knowledge of the increase of the white cells is of assistance in determining the severity of the infection, and the degree of resistance being offered by the body. This requires not only an absolute count, *i.e.*, the total number of white cells in a cubic millimeter of blood, but also the differential count, *i.e.*, the relative number of each type of leucocytes, particularly the number of neutrophiles. In making

[10] From *opsono*, I prepare food for. The opsonin content of the blood can be determined experimentally and is called the *opsonic index*.

a differential count the number of each kind of white cells in a hundred is counted. A high absolute count, with a high neutrophile percentage, indicates severe infection and good body resistance. A high absolute count, with a moderate polynuclear percentage, indicates a moderate infection and good resistance. A low absolute count, with a high polynuclear percentage, indicates severe infection and weak resistance.

Life cycle of white cells. — We do not know the term of existence of the white cells, or where they are destroyed, except that large numbers are lost in the battle waged against bacteria, others by hemorrhage, and others may be converted into granulation tissue.

Blood-platelets or thrombocytes. — They are disc-shaped bodies. In edge view, they appear as short rods; in face view, they appear as round plates. They are smaller than the red corpuscles. The average number is 300,000 per cu. mm. of blood. When removed from the blood, they agglutinate and disintegrate very rapidly unless an anticoagulant is added.

Function. — It is thought that the blood-platelets help in the clotting of blood. When exposed to air and rough surfaces (conditions accompanying a wound and hemorrhage) large numbers of blood-platelets are disintegrated and set free a substance known as tissue extract. They also help to furnish the blood with prothrombin. Both of these substances are essential to clotting.[11]

Plasma. — The plasma of the blood is a complex fluid of a clear amber color containing a great variety of substances as might be inferred from its double relation to the cells, ~~serving as~~ a source of nutrition and ~~as~~ a means of removing the waste products that result from their functional activity. Consult table included in summary, page 243.

Water. — About nine-tenths of the plasma is water. This proportion is kept fairly constant by kidney activity coupled with the continual exchanges of fluid which take place between the blood, the lymph, and the cells.

Blood-proteins. — Three proteins are usually described as existing in the plasma of circulating blood, *i.e.*, fibrinogen, serumglobulin, and serum-albumin, but there are indications that the actual number of proteins is much greater. The first two of these proteins belong to the group of globulins and hence have many properties in common. Serum-albumin belongs to the group of albumins[12] of which white of egg constitutes another member. With the exception of fibrinogen, we know little of their mode of origin,

[11] The active principle of tissue extract has been given various names; for instance, thromboplastin, thrombokinase, cytozyme (Bordet), cephalin, etc.

[12] Albumins and globulins give the same general tests; they are both coagulated by heat, and the chief difference is in their solubilities.

place of formation, and the particular value of each in the body. Under proper conditions fibrinogen gives rise to fibrin. It is thought that fibrinogen is produced in the liver.

Nutrients. — These are the end products resulting from the digestion of food; amino-acids derived from proteins; glucose derived from carbohydrates; and fats. Under normal conditions amino-acids are present in a small proportion; glucose and fat are present in about the same proportion, *i.e.*, 0.08 to 0.18 per cent. A temporary increase in the amount may follow the ingestion of a large quantity.

Salts. — The salts found in the blood are derived from food and from the chemical reactions going on in the body. The most abundant is sodium chloride.

Waste substances. — Purine bases, urea, uric acid, creatinine, and many other waste substances thrown off from the cells are in the blood on their way to be excreted by the kidneys or other organs of elimination.

Gases. — Dissolved gases, oxygen, nitrogen, and carbon dioxide, are found in the blood. Carbonic acid is continually entering the blood from the tissues, but the blood contains certain buffer substances, *i.e.*, sodium bicarbonate, sodium phosphate, and proteins which enter into loose combination with the carbon dioxide so that only a small per cent is present in simple solution.

Special substances. — The blood serves as a medium to carry endocrines or internal secretions and enzymes, also antithrombin, antiprothrombin, and prothrombin.

Antibodies. — This term is applied to substances which are antagonistic to invading organisms. Recovery from many infections is due to an accumulation of these substances in the blood, and to the success of the phagocytes in destroying the invading organisms. When bacteria enter the body, they stimulate [13] the production of antibodies. Antibodies may be classified as (1) lysins, which act by dissolving organisms, (2) opsonins, which aid the white cells by sensitizing or preparing the organisms for ingestion, and (3) agglutinins [14] which clump the organisms in masses. Antitoxins are also classed as antibodies, because they neutralize the toxins formed by pathogenic organisms. The antibodies existing in the blood at any given time depend upon the condition of health, freedom from infection, etc.

[13] Anything which stimulates the formation of antibodies is called an antigen.

[14] Agglutinins are also called precipitins. Agglutination tests are used for diagnostic purposes in various diseases, *e.g.*, typhoid, cholera, undulant fever, and tularemia.

Functions of the blood. — Blood is spoken of as the nutritive fluid of the body. It is more than a nutritive fluid, as can be seen from these functions as commonly listed.

1. It carries oxygen from the lungs to the tissues.
2. It carries food material absorbed from the intestines to the tissues.
3. It carries products formed in one tissue to other tissues where they are used. In other words, it carries hormones and internal secretions.
4. It carries the waste products of metabolism to the organs of excretion — the lungs, kidneys, intestines, and skin.
5. It aids in maintaining the temperature of the body at the normal level.
6. It aids in maintaining the normal acid-base balance of the tissues.
7. The white blood cells constitute a defense mechanism against the invasion of harmful organisms.
8. It aids in maintaining water content.
9. It clots, maintaining vascular integrity after trauma.

THE CLOTTING OF BLOOD

Blood when drawn from the blood-vessels of a living body is perfectly fluid. In a short time it becomes viscid, and this viscidity increases rapidly until the whole mass of blood becomes a soft jelly. If the blood in this jelly stage is left untouched in a glass vessel, a few drops of an almost colorless liquid soon make their appearance on the surface of the jelly. Increasing in number and running together, the drops after a while form a superficial layer of pale straw-colored liquid. Later on, similar layers of the same liquid are seen at the sides, and finally at the bottom of the jelly, which shrinks to a smaller size and firmer consistency, and forms a *clot*, floating in a liquid which is called *blood serum*, which is blood minus the fibrin and cells. If a portion of the clot is examined under the microscope, it is seen to consist of a network of fine needle-like fibers in the meshes of which are entangled the red and some of the white cells. In the soft jelly stage of the clot, both the red and white

FIG. 136. — BOWL OF RECENTLY CLOTTED BLOOD, SHOWING THE WHOLE MASS UNIFORMLY SOLIDIFIED. (Dalton.)

cells are caught in the fibrin network. As the clot shrinks and becomes smaller, the red cells are held more firmly, but some of the white cells, due to their power of ameboid movement, escape into the serum. The needle-like fibers are composed of fibrin. Many theories have been advanced to account for the formation of the insoluble fibrin, from soluble fibrinogen. The exact process is not known, but it is thought to be comparable to the clotting of milk under the influence of rennin. According to Howell[15] the blood contains two substances — antithrombin and antiprothrombin (heparin) — concerned with preventing the clotting of blood in the blood-vessels, and three substances concerned with the clotting of blood. The latter are (1) fibrinogen, (2) calcium salts, and (3) prothrombin (thrombogen). When blood clots, prothrombin, and calcium salts form thrombin, thrombin changes fibrinogen to fibrin, which is insoluble. The fibrin and the blood cells form the clot. This may be represented in diagrammatic form as follows:

FIG. 137. — BOWL OF CLOTTED BLOOD AFTER TWELVE HOURS, SHOWING THE CLOT CONTRACTED AND FLOATING IN THE FLUID SERUM. (Dalton.)

Cellular elements of blood and tissues ⟶ tissue extract.
Tissue extract neutralizes antithrombin and antiprothrombin.
Prothrombin + calcium ⟶ thrombin.
Thrombin + fibrinogen ⟶ insoluble fibrin.
Fibrin + cells of blood ⟶ clot.

For the blood to clot,[16] the two agents concerned with the prevention of clotting must be neutralized. (1) Antiprothrombin prevents prothrombin changing to thrombin, and (2) antithrombin prevents the action of the thrombin upon fibrinogen. These substances are neutralized by tissue extract which is set free by the crushed tissue cells, the blood corpuscles, and the platelets or thrombocytes. This accounts for the fact that blood clots only when tissues are wounded.

Value of clotting. — This property is of very great importance in the arrest of hemorrhage. The clot formed closes the openings of wounded vessels. The procedures used to check hemorrhage are directed toward hastening the formation of a clot, and stimulating the blood-vessels to contract so that a smaller-sized clot will be sufficient.

The time it takes for the blood of human beings to clot is usually about 5 minutes.[17] In rare individuals the blood does not clot

[15] Dr. William H. Howell, The Johns Hopkins University.

[16] Other theories are also given in the more detailed works on Physiology.

[17] Estimation of coagulation time is important as a preliminary to operation when there is any reason to expect dangerous capillary oozing, as in tonsillectomies or operations upon jaundiced persons.

readily or at all, so that any injury or operation involving hemorrhage is dangerous. This condition is called *hemophilia,* and such an individual is called a *hemophiliac.* Only males suffer from this condition. Females are exempt, but they may transmit it to their male offspring.

Conditions affecting clotting. — Clotting is *hastened* by:

(1) Injury to the walls of the blood-vessels.

(2) Contact with a rough surface or any foreign substance. Clotting is hastened when gauze or like substance is put into a wound.

(3) The venom of certain snakes.

(4) A temperature above 46° C. (116° F.), *e.g.*, the use of hot towels to check bleeding from the stump of an amputated limb; the use of hot douches to check postpartum hemorrhage.

(5) Rest tends to prevent the dislodgment of clots forming at the opening of vessels. If blood is contained in a dish, agitation hastens the disintegration of the thrombocytes and thus favors the formation of tissue extract.

Clotting is *hindered* by:

(1) Contact with the smooth lining of the heart and blood-vessels.

(2) A deficiency of the normal calcium salts.

(3) The addition of citrates [18] or oxalates to the blood, because they interact with the calcium.

(4) A very low temperature. Cold hinders the formation of a clot, but is often used to check hemorrhage, because it stimulates the blood-vessels to contract.

(5) A deficiency or abnormal condition of thrombocytes.

(6) Concentrated solutions of such salts as magnesium sulphate, sodium sulphate, and sodium fluoride.

(7) If bile [19] gets into the blood, as in jaundice or cirrhosis of the liver, clotting is retarded.

(8) The injection into the blood of such organic ferments as pepsin, trypsin, leech extracts, and the venom of certain snakes.

(9) Absence of fibrinogen.

(10) Removal of fibrin. If fresh blood, before it has time to clot, be whipped with a bundle of twigs, the fibrin will form on the twigs and if the whipping of the blood be continued until all the fibrin has been deposited on the twigs, the blood left in

[18] In transfusions the donor's blood is often rendered incoagulable as it is withdrawn by adding sodium citrate. It is then injected into the vein of the patient.

[19] A person who is jaundiced may have a severe hemorrhage from a slight wound.

the vessel will be found to have lost the power of clotting. Such blood is called **defibrinated.**

(11) If blood is received into a receptacle that is coated with oil or paraffin, clotting is retarded.

Why blood does not clot within the blood-vessels. — In accordance with the theory of clotting which we have considered, blood does not clot within the blood-vessels because of: (1) the absence of tissue extract and (2) the presence of antiprothrombin and antithrombin.

Intravascular clotting. — It is well known that clots occasionally form within the blood-vessels. The most frequent causes are:

(1) Any foreign material, even air, that is introduced into the blood and not absorbed, may stimulate the formation of thrombin and a clot.

(2) When the internal coat of a blood-vessel is injured, as for instance by a ligature or the bruising incidental to operations, the endothelial cells are altered and may act as a foreign substance. If in addition there is a stasis of blood at this point, disintegration of the blood-platelets and white cells may result in the formation of thrombin and a clot. The products of bacteria and other toxic substances may injure the lining of a blood-vessel and produce the same result.

Thrombus and embolus. — A clot which forms inside a blood-vessel is called a thrombus and the condition is called thrombosis. A thrombus may be broken up and disappear, but the danger is that it may lodge in the heart or certain parts of the brain, where it acts as a plug, blocks circulation, and causes instant death. A thrombus that becomes dislodged from its place of formation is called an embolus. Such a condition is called embolism.

Regeneration of the blood after hemorrhage. — A large portion of the total amount of blood in the body may be lost suddenly by hemorrhage without producing a fatal result. It is probable that a healthy individual may recover from the loss of as much as three per cent of the body weight. Experiments on lower animals show that the plasma of the blood regains its normal volume within a few hours after a slight hemorrhage, and in from twenty-four to forty-eight hours if the loss of blood has been severe; but the number of red cells and hemoglobin are restored more slowly, getting back to normal after a number of days or even weeks.

When the need for an increased volume of blood is urgent, hypodermoclysis, intravenous infusion, or transfusion may be practiced.

Hypodermoclysis means the injection of fluids into the subcutaneous tissue. The fluid most frequently used is physiological salt solution, *i.e.*, a 0.9 per cent solution of sodium chloride. The solution is introduced where there is loose tissue to favor absorption of fluid, *e.g.*, the skin of the abdomen, below the breast, in the thighs, buttocks, or in the axillary line.

Intravenous infusion is the injection of a solution directly into a vein. Physiological salt solution and various others [20] are used for this purpose.

[20] Locke's Solution contains —

Sodium Chloride	0.9 gm.
Potassium Chloride	0.042 gm.
Calcium Chloride	0.024 gm.
Sodium Bicarbonate	0.03 gm.
Dextrose	0.1 gm.

Distilled water sufficient to make 100 cc.

Ringer's Solution contains —

Sodium Chloride	0.7 gm.
Calcium Chloride	0.025 gm.
Potassium Chloride	0.03 gm.

Distilled water to make 100 cc.

Sometimes a combination of these two, called the Ringer-Locke Solution, is used. This is Locke's Solution with the dextrose omitted.

The veins into which the solution may be introduced are the cephalic or median basilic vein (vena mediana cubiti), which is usually the largest, the most prominent, and nearest to the surface of the arm.

The disadvantage of intravenous infusion of normal saline is that its good effects are temporary, water being rapidly lost to the tissues, rendering them edematous. Sometimes solutions like gum arabic, having the same viscosity as the blood, may be used after they are made isotonic by the addition of sodium chloride. Infusion of such solutions is said to give more permanent and satisfying results.

Transfusion is the transfer of blood from one person (the donor) to another (the recipient). Before blood is used several laboratory tests are necessary: (1) A Wassermann test to exclude the possibility of conveying syphilis. (2) A

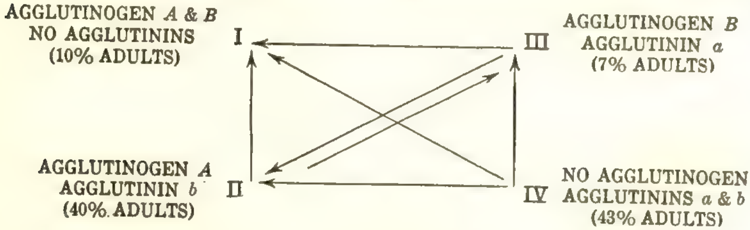


FIG. 138. — DIAGRAM TO SHOW THE MOSS SYSTEM OF ISOAGGLUTINOGEN GROUPS FOR "BLOOD MATCHING." Red cells have two agglutinogens *A* and *B*, making it possible for them to be agglutinated. Plasma has two agglutinins *a* and *b*. For blood to become agglutinated, an agglutinogen and agglutinin of the same letter must come together; cells having agglutinogen *A* will be agglutinated only by plasma containing agglutinin *a*, etc. For instance, the red cells of a person of group II (*Ab*) will be agglutinated by plasma of a person of group III (*Ba*) or of group IV (*ab*) since the plasma of both groups contain agglutinin *a* but will not be agglutinated by plasma of group I (*AB*) or of its own group, group II, since the plasma of these groups does not contain agglutinin *a*. Note that the red cells of group I (*AB*) will be agglutinated by plasma of all other groups and that since group IV (*ab*) contains no agglutinogens, its cells will not be agglutinated by any of the other groups. Other groups have been described.

In transfusion recipient and donor should belong to the same group. In emergency, blood of group IV (*ab*) may be used for any of the other three groups since if it is introduced into blood of recipient very slowly it will be so greatly diluted as not to agglutinate recipient's red cells, and having no agglutinogens cannot be agglutinated by the blood of any other group. Group IV is called *universal donor*. Group I is called *universal recipient;* since it has no agglutinins it cannot agglutinate the blood of any other group.

test to determine whether the blood of the donor and the blood of the recipient fall in the same group. (3) Another test is for isohemolysins or poisons in the serum which would hemolyze red cells.[21]

Clotting is prevented in various ways. (1) Anastomoses may be made between the blood vessels of the donor and the recipient, so that the blood passes from one to the other without coming into contact with a foreign surface. (2) A simpler method is to withdraw the donor's blood into a flask containing sodium citrate, which prevents clotting. It is then injected into the vein of the recipient in the same way as saline solution.[22]

[21] Some authorities consider this unnecessary, as, if isoagglutinins are absent, it is thought isohemolysins will be absent also.

[22] All of these procedures are carried out with as nearly perfect asepsis as possible.

Blood matching. — It has been shown that human blood can be classified into four groups: 10 per cent of adults fall into Group I

Whole Blood	SERUM Group I	II	III	IV
I	O	Ag	Ag	Ag
II	O	O	Ag	Ag
III	O	Ag	O	Ag
IV	O	O	O	O

FIG. 139. — BLOOD TYPING. As indicated above, for transfusion the blood of recipient and of donor *must be typed.* To do this, add a drop of blood diluted with citrated saline to *serum* of *known type* and watch for agglutination or "clumping."

Ag indicates clumping; *O* indicates no clumping. It will be noted that in practice it is necessary *only* to add blood to serum II and III for typing. Why?

(Moss), 40 per cent into Group II, 7 per cent into Group III, and 43 per cent into Group IV. When transfusing, the blood of the donor and the recipient should fall in the same group.

SUMMARY

Liquid Tissues
- Cells.
- Intercellular liquid.

E **Blood**
- 1. **Description**
  - Color
    - Bright red in arteries.
    - Dark red in veins.
  - Sticky fluid.
  - ~~Specific gravity~~ varies between 1.041 and 1.067.
  - Reaction varies from pH 7.38 to 7.4.
  - ~~Temperature~~, 38.5° C.
  - Peculiar odor. Salty taste.
  - $\frac{1}{20}$ of the body weight.
- **Composition**
  - Cells about $\frac{1}{2}$ of volume
    - a. Red, or erythrocytes.
    - b. Leucocytes
      - 1 Lymphocytes
      - 2 Monocytes
      - 3 Granular leucocytes
    - c. Blood-platelets ~~or thrombocytes.~~
  - Plasma, about $\frac{1}{2}$ of volume — intercellular liquid.

Red Cells
- **Description**
  - Biconcave discs about 7.7 μ in diameter.
  - Stroma containing hemoglobin
    - Non-protein, is named hematin.
    - Protein, named globin.
  - Have no nuclei.
  - Soft, flexible, and elastic.
- **Number**
  - Cubic millimeter of blood contains about
    - 5,000,000 for men.
    - 4,500,000 for women.
    - Varies even in health.
  - Polycythemia — increase above normal.
  - Anemia — deficiency of red cells or deficiency of hemoglobin in the cells.

- **Red Cells**
  - **Function**
    - Oxygen carriers.
    - Color due to oxygen in combination with hemoglobin.
  - **Hemolysis** — Loss of hemoglobin from the red cells is called hemolysis.
  - **Life Cycle**
    - Before birth — originate in liver, spleen, and red marrow.
    - After birth may originate in endothelial cells of blood capillaries or in red marrow of bones.
    - Lose their nuclei before being forced into the circulation, which suggests that their term of existence is short.
    - Disintegrate
      1. Undergo hemolysis in blood stream.
      2. Destroyed in spleen, lymph-nodes, and liver.
- **White Cells**
  - **Description**
    - Minute masses of nucleated protoplasm.
    - Variable in size, sometimes smaller than red cells, majority are larger.
    - Gray (not white) in color.
  - **Number**
    - Cubic millimeter of blood
      - 5000 to 7000.
      - Increase = leucocytosis.
      - Decrease = leucopenia.
  - **Varieties**
    - Lymphocytes
      - (a) Small.
      - (b) Large.
    - Monocytes
      - (a) Large mononuclear.
      - (b) Transitional.
    - Granular leucocytes
      - (a) Polymorphonuclear or neutrophiles.
      - (b) Eosinophiles or acidophiles.
      - (c) Mast-cells or basophiles.
  - **Functions**
    - Supposed to be different for different forms.
    1. Protect the body from pathogenic bacteria.
    2. Promote tissue repair.
    3. Aid in absorption from intestines.
    4. Take part in the clotting of blood.
    5. Probably help to form typical blood-proteins.
  - **Life Cycle**
    - Lymphocytes arise from the reticular tissue of the lymph-nodes of body.
    - Granular leucocytes arise from cells of bone marrow.
    - Numbers lost in
      - (1) Battles against bacteria.
      - (2) Hemorrhage.
      - (3) Formation of granulation tissue.
- **Inflammation**
  - (1) Irritation resulting from injury or infection.
  - (2) Increased supply of blood.
  - (3) Engorgement of blood-vessels.
  - (4) Migration of white cells.
  - (5) Exudation of plasma.
  - (6) Red cells forced through capillary walls.
  - **Symptoms**
    - Pain.
    - Heat.
    - Redness.
    - Swelling.
    - Loss of function.

- **Inflammation**
  - **Result**
    - (*a*) Resolution — White cells eat up bacteria, clear up debris, and return to blood.
    - (*b*) Suppuration — Bacteria destroy white cells and form pus.
    - (*c*) Pus consists of
      - Bacteria
        - Dead.
        - Living.
      - Phagocytes.
      - Disintegrated tissue cells.
      - Exudate from blood-vessels.

- **Blood-platelets or Thrombocytes**
  - **Description**
    - Disc-shaped bodies. Always smaller than red or white cells.
    - Origin, fate, and function are open questions.
    - Assist in clotting of blood.

- **Plasma** 3e
  - a **Water** — About 90 per cent.
  - **Blood-proteins**
    - Fibrinogen.
    - Serumglobulin.
    - Serum-albumin.
  - **Nutrients**
    - Proteins.
    - Carbohydrates.
    - Fats.
  - **Salts**
    - Chlorides, Sulphates, Phosphates, Carbonates of Sodium, Calcium, Magnesium, Potassium, Iron — Nutrients, wastes or regulatory substances.
  - **Waste Substances**
    - Purine bases.[23]
    - Urea.
    - Uric Acid.
    - Creatine.
    - Creatinine.
  - **Gases**
    - Oxygen.
    - Carbon dioxide — waste or regulatory.
    - Nitrogen.
  - **Special Substances**
    - Endocrines — Antithrombin — antiprothrombin.
    - Enzymes — Prothrombin.
  - **Antibodies**
    - Lysins — dissolve bacteria.
    - Opsonins — prepare bacteria for ingestion.
    - Agglutinins — clump bacteria in masses.
    - Antitoxins — neutralize toxins.

- **Functions of Blood** 4
  - Carries oxygen from lungs to tissues.
  - Carries food material to tissues.
  - Carries hormones and internal secretions.
  - Carries waste products to organs of excretion.
  - Aids in maintaining normal temperature.
  - ~~Aids in maintaining acid-base balance of tissues.~~
  - White cells constitute defense mechanism against infection.
  - ~~Aids in maintaining~~ internal fluid pressure.
  - Aids in maintaining vascular integrity after trauma.

[23] This list is by no means complete.

Clotting

- **Serum** — Blood minus fibrin and cells.
- **Theory**
  - Blood contains two substances concerned with preventing the clotting of blood in the blood-vessels, namely, antithrombin and antiprothrombin.
  - Blood contains three substances concerned with the clotting of blood, namely, fibrinogen, calcium salts, and prothrombin.
- **Process**
  - Cellular elements of blood and tissues ⟶ tissue extract.
  - Tissue extract neutralizes antithrombin and antiprothrombin.
  - Prothrombin + calcium ⟶ thrombin.
  - Thrombin + fibrinogen ⟶ insoluble fibrin.
  - Fibrin + cells of blood ⟶ clot.
- **Value** — Checks hemorrhage.
- **Hastened by**
  1. Injury to the walls of the vessels.
  2. Contact with a rough surface or any foreign material.
  3. The venom of certain snakes.
  4. A temperature above 116° F.
  5. Rest.
  6. Agitation.
- **Hindered by**
  1. Contact with smooth lining of vessels.
  2. A deficiency of the normal calcium salts.
  3. The addition of citrates or oxalates to the blood.
  4. A very low temperature.
  5. A deficiency or abnormal condition of the thrombocytes.
  6. Concentrated solutions of magnesium sulphate, sodium sulphate, and sodium fluoride.
  7. Bile in the blood.
  8. Injection of organic ferments.
  9. Absence of fibrinogen.
  10. Removal of fibrin.
  11. Received in vessel coated with oil or paraffin.

Intravascular Clotting

- **Theory to account for rare occurrence**
  - Absence of tissue extracts.
  - Presence of antithrombin and antiprothrombin.
- **Causes**
  - Any foreign material introduced into blood and not absorbed will stimulate clotting.
  - Injury to internal coat of blood-vessels.
- **Thrombus** — Name given to clot which forms inside vessel.
- **Embolus** — A thrombus that has become dislodged from place of formation.

Regeneration of blood after hemorrhage — Plasma is regenerated rapidly, red cells within a few days or weeks.

Treatments to increase volume of blood

- **Hypodermoclysis** — injection of fluids into subcutaneous tissue.
- **Intravenous infusion** — injection of solution into vein.
- **Transfusion** — transfer of blood from one person to another.

5

Blood Matching	Group I — 10% of adults — universal recipient. Group II — 40% of adults. Group III — 7% of adults. Group IV — 43% of adults — universal donor.

Blood Typing Moss	Unknown *blood* to be typed, after dilution with citrated saline, is added to *known* Group II and Group III *serum*.	
	Unknown belongs to	Group I — clumping in Group II serum and in Group III serum. Group II — clumping in Group III serum only. Group III — clumping in Group II serum only. Group IV — no clumping.

CHAPTER XII

THE BLOOD VASCULAR SYSTEM

The blood is contained in branched tubes. It is driven along these tubes by the action of the *heart,* which is a hollow muscular organ placed in the center of the vascular system. One set of vessels — the *arteries* — conducts the blood out from the heart and distributes it to the different parts of the body, whilst other vessels — the *veins* — bring it back to the heart again. From the arteries the blood flows through a network of fine vessels — the capillaries (small, hair-like) — into the veins.

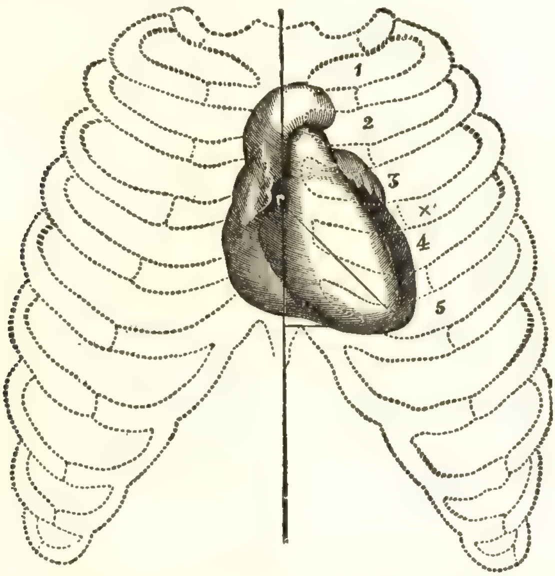


FIG. 140. — HEART *in situ,* 1, 2, 3, 4, 5, intercostal spaces; vertical line represents median line. The space outlined by the triangle indicates the superficial cardiac region; *x* shows the location of the nipple on the fourth rib. (Dalton.)

HEART

The heart is a hollow, muscular organ, situated in the thorax between the lungs, and above the central depression of the diaphragm. It is about the size of the closed fist, shaped like a blunt

cone, and so suspended by the great vessels that the broader end or base is directed upward, backward, and to the right. The pointed end or apex points downward, forward, and to the left. As placed in the body, it has a very oblique position, and the right side is almost in front of the left. The impulse of the heart against the chest wall is felt in the space between the fifth and sixth ribs, a little below the left nipple, and about 8 cm. (3 in.) to the left of the median line.

Pericardium. — The heart is covered by a membranous sac called the pericardium (around the heart). It consists of two parts: (1) an external fibrous portion, and (2) an internal serous portion.

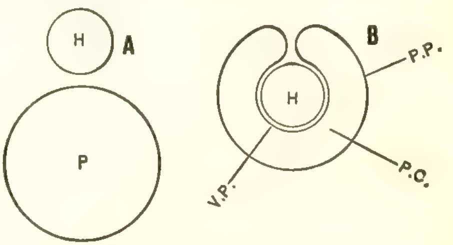


FIG. 141. — DIAGRAM OF THE HEART AND SEROUS PERICARDIUM. *A*, shows heart and pericardium lying separately. *B*, shows the pericardium invaginated by the heart. *V.P.*, shows visceral layer that clings close to the heart muscle. *P.P.*, shows parietal layer that lines the fibrous pericardium. *P.C.*, pericardial cavity which in actual conditions is a very narrow space filled with pericardial fluid.

(1) The **external fibrous** pericardium is composed of white fibrous tissue, and is attached by its upper surface to the large blood-vessels which emerge from the heart. It covers these vessels for about 3.8 cm. ($1\frac{1}{2}$ in.) and blends with their sheaths. The lower border is firmly adherent to the diaphragm, and the front surface is attached to the sternum by means of fibrous bands.

(2) The **internal or serous portion** of the pericardium is a completely closed sac; it envelops the heart and lines the **fibrous** pericardium. The heart, however, is not within the cavity of the closed sac. (See Fig. 141.) The portion of the serous pericardium which lines and is closely adherent to the heart is called the visceral portion (*viscus*, organ); the remaining part of the serous pericardium, namely, that which lines the fibrous pericardium, is known as the parietal portion (*paries*, a wall). The visceral and parietal portions of this membrane are everywhere in contact. The contiguous surfaces are lined by smooth serous membrane, and are moistened by a small quantity of pericardial fluid. Owing to the constant contractions of the heart, these surfaces are continually sliding one upon the other, and are admirably constructed to prevent friction.

Endocardium. — The inner surface of the cavities of the heart is lined by smooth serous membrane called *endocardium*. It covers

the valves, surrounds the chordæ tendineæ, and is continuous with the lining membrane of the large blood-vessels. Inflammation of this membrane is called *endocarditis*.

Myocardium. — The main substance of the heart is cardiac muscular tissue, which is called *myocardium*. This tissue includes the muscle bundles of (1) the atria (auricles), (2) the ventricles, and (3) the atrioventricular bundle (of His).[1]

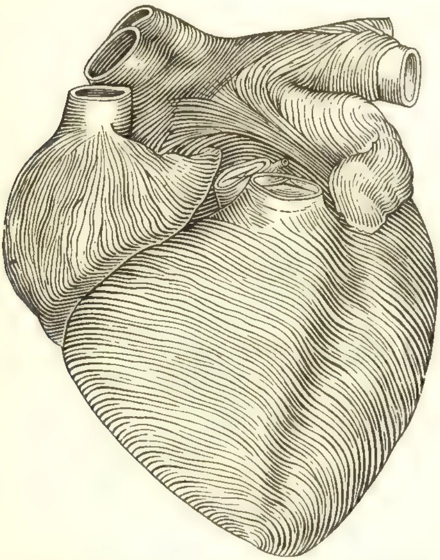


Fig. 142. — Anterior View of Heart, Dissected, after Long Boiling, to Show the Superficial Muscles of the Myocardium. (Quain.)

(1) The principal muscle bundles of the atria radiate from the area which surrounds the orifice of the superior vena cava. One, the interatrial bundle, connects the anterior surfaces of the two atria. Other than this, the muscle bundles are confined to their respective atria, though they merge more or less.

(2) The muscle bundles of the ventricles arise from the tendinous structure at the base of the ventricles and converge in spiral turns toward the apex, where they turn upward and are inserted into the same tendinous structures on the opposite side.

(3) The muscular tissue of the atria is not continuous with that of the ventricles. The walls are connected by fibrous tissue and the atrioventricular bundle of modified muscle cells. This bundle arises in connection with the atrioventricular (*A–V*) node, which lies near the orifice of the coronary sinus in the right atrium. From this node the atrioventricular bundle passes forward to the membranous septum between the ventricles where it divides into right and left bundles, one for each ventricle. In the muscular septum between the ventricles each bundle divides into numerous strands, which spread over the internal surface just under the endocardium. The greater part of the atrioventricular bundle consists of spindle-

[1] William His, Swiss anatomist, 1831–1904.

shaped muscle cells. The significance of the atrioventricular bundle is discussed on page 300.

The cavities of the heart. — The heart is divided from the base to the apex, by a fixed partition, into a right and left half, frequently called right and left heart. ~~The two sides of the heart have no communication~~ with ~~each~~ other after birth. The right

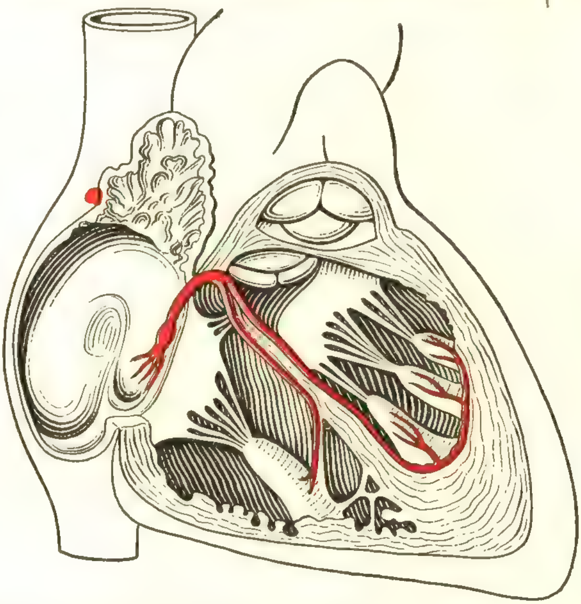


FIG. 143. — DIAGRAM OF THE ATRIOVENTRICULAR BUNDLE OF HIS. The atrioventricular node can be seen near the opening of the coronary sinus in the right auricle. The bundle divides. The two branches run down in the ventricular septum and give off many smaller branches to the papillary muscles and to the muscular walls of the ventricles. Only a few of the branches are shown. Bundle indicated in red. Part of the sinu-atrial node is seen in red between the base of the superior vena cava and the right auricular appendix.

side contains *venous*, and the left side *arterial*, blood. Each half is subdivided into two cavities, the upper, called *atrium* (auricle); the lower, *ventricle.*

The walls ~~of the~~ atria are thinner than the walls of the ventricles, and the wall of the left ventricle is thicker than that of the right (the proportion being as 3 to 1). This difference is accounted for by the greater amount of work the ventricles, as compared with the atria, have to do.

Muscular columns, called the *trabeculæ carneæ* (*columnæ carneæ*), project from the inner surface of the ventricles. They are of three kinds: (1) the first are attached along their entire length and form

ridges or columns; (2) the second are attached at their extremities, but are free in the middle, and (3) the third are the so-called *papillary muscles*, which are continuous with the wall of the ventricle by their bases. The apices give rise to fibrous cords, called the *chordæ tendineæ*, which are attached to the cusps of the valves.

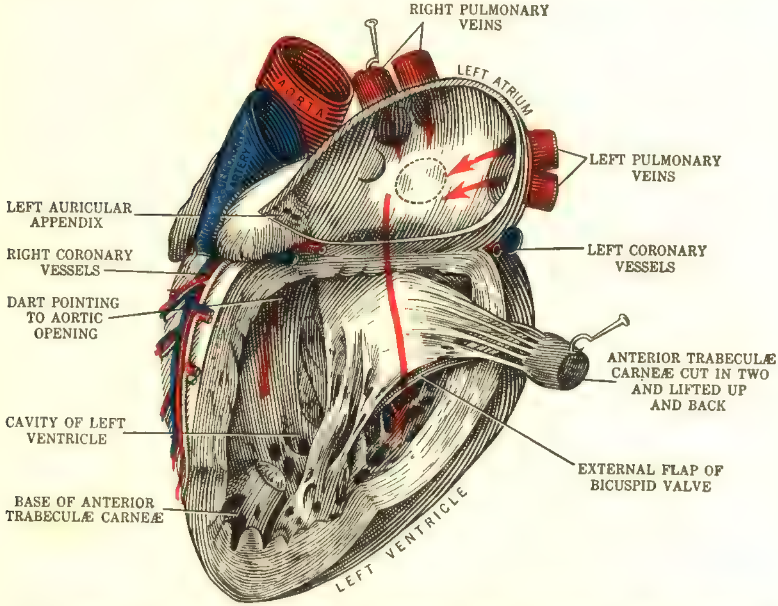


FIG. 144. — LEFT ATRIUM AND VENTRICLE, THE DORSAL WALL OF EACH HAVING BEEN REMOVED. The trabeculæ carneæ are muscle columns which project from nearly the whole of the inner surface of the ventricles. Some of them give origin to the papillary muscles. (Gerrish.)

Important orifices of the heart. — Eight large blood-vessels are connected with the heart. These eight orifices plus the two between the atria and ventricles make a total of ten.

On the right side of the heart, the superior and inferior venæ cavæ empty into the atrium, and the pulmonary artery leaves the ventricle.

On the left side of the heart, four pulmonary veins empty into the atrium, and the aorta leaves the ventricle. ~~There are~~ some ~~smaller openings to receive blood directly~~ from the heart ~~substance,~~ and before birth there is an opening between the right and ~~left atria~~ called the *foramen ovale*. ~~Normally this closes~~ soon after ~~birth~~.

Valves of the heart. — Between each atrium and ventricle there is a constricted opening, the ~~atrioventricular~~ orifice, which is

strengthened by fibrous rings and protected by valves. The openings into the aorta and pulmonary artery are also guarded by valves.

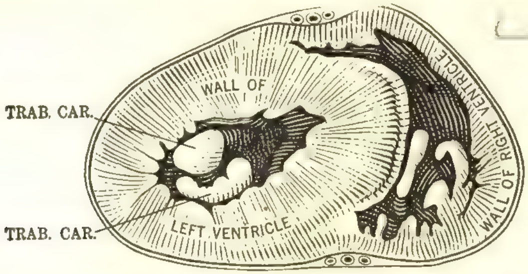


FIG. 145. — CROSS-SECTION THROUGH BOTH VENTRICLES, SHOWING THE SHAPE OF THEIR CAVITIES AND THE RELATIVE THICKNESS OF THEIR WALLS. Trab. Car., trabeculæ carneæ. (Gerrish.)

The tricuspid valve. — The valve guarding the right atrio-ventricular opening is composed of three irregular-shaped flaps, or cusps, and hence is named tricuspid. The flaps are mainly formed of fibrous tissue covered by endocardium. At their bases they are continuous with one another, and form a ring-shaped membrane around the margin of the atrial opening: their pointed

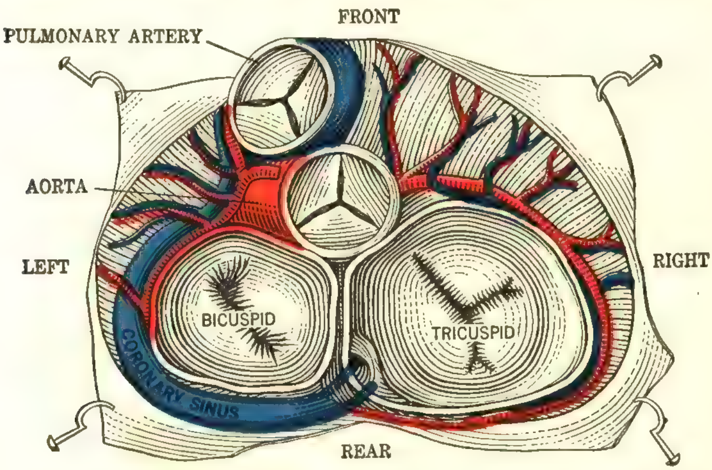


FIG. 146. — VALVES OF THE HEART AND GREAT ARTERIES, VIEWED FROM ABOVE, THE ATRIA HAVING BEEN REMOVED. (Gerrish.)

ends or apices project into the ventricle, and are attached by cords, the *chordæ tendineæ*, to small muscular pillars, the *papillary muscles* in the interior of the ventricles.

The bicuspid valve. — The valve guarding the left atrial opening consists of only two flaps or cusps, and is named the bicuspid,

or mitral valve. It is attached in the same manner as the tricuspid valve, which it closely resembles in structure, except that it is much stronger and thicker in all its parts. Chordæ tendineæ are attached to the cusps and papillary muscles in the same way as on the right side; they are less numerous but thicker and stronger.

Function. — The tricuspid and bicuspid valves oppose no obstacle to the passage of the blood from the atria into the ventricles because the free edges of the flaps are pointed in the direction of the blood current; but any flow forced backward gets between the flaps and the walls of the ventricles, and drives the flaps upward, until, meeting at their edges, they unite and form a complete transverse partition between the atria and ventricles. Being restrained by the chordæ tendineæ, the expanded flaps of the valves resist any pressure of the blood which might otherwise force them to open into the atria; at the same time the papillary muscles, to which the chordæ tendineæ are attached, contract and shorten, thus keeping the chordæ tendineæ taut.

Semilunar valves. — The orifice between the right ventricle and the pulmonary artery is guarded by the *pulmonary valve,* and the orifice between the left ventricle and the aorta is guarded by the *aortic valve.* These two valves are called semilunar valves and consist of three half-moon-shaped pockets, each pocket being attached by its convex margin to the inside of the artery where it joins the ventricle, while its free border projects into the lumen of the vessel. Small nodular bodies, called the *corpora Arantii,*[2] are attached to the center of the free edge of each pocket.

Opposite the valves the aorta presents slight dilatations called the aortic sinuses, or sinuses of Valsalva.[3]

Function. — The semilunar valves offer no resistance to the passage of blood from the heart into the arteries, as the free borders project into the arteries, but they form a complete barrier to the passage of blood in the opposite direction. In this case each pocket becomes filled with blood, and the free borders are floated out and distended so that they meet in the center of the vessel. The *corpora Arantii* assist in the closure of these valves and help to make the barrier perfect.

The orifices between the two caval veins and the right atrium and the orifices between the left atrium and the four pulmonary veins are not guarded by valves, with the possible exception of the

[2] Julius Cæsar Arantius, Italian anatomist, 1530–1589.
[3] Antoine Marie Valsalva, Italian anatomist, 1666–1723.

opening into the inferior vena cava, which is partly covered by a membrane known as the Eustachian valve.

Blood supply. — Just above the ~~attached margins of the aortic valve~~, the aorta gives off two branches, called the *right* and *left coronary* arteries. They encircle the heart like a crown, ~~hence their name~~. They supply the substance of the heart with blood, as the blood contained within the cavities of the heart only nourishes the endocardium. The blood distributed by the coronary arteries is returned by two sets of veins (1) those which return the blood to the coronary sinus — a wide venous channel (2.25 cm.

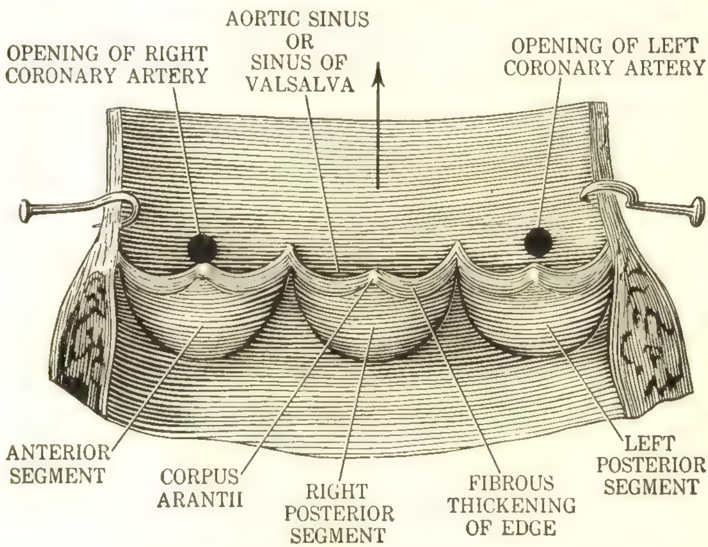


FIG. 147. — AORTIC VALVE. The artery has been cut open between the anterior and left posterior segments, and spread out. (Gerrish.)

long), emptying into the right atrium ; (2) three or four small veins return the blood directly to the right atrium. A few of the smallest veins [4] empty into the atria and ventricles.

Nerve supply. — The heart is supplied with two sets of motor nerve fibers. One set reaches the heart through the *vagus* nerves ~~of the craniosacral system~~. They slow or stop the heart beat and are called *inhibitory*. The ~~other set passes~~ to the heart by way of ~~the~~ spinal cord and thoracolumbar system. They quicken and ~~augment~~ the heart beat and are called *accelerator*. Both sets are connected with the cardiac center in the medulla oblongata, and through this center either set may be stimulated.

[4] These are called veins of Thebesius. Adam Christianus Thebesius, German physician, 1686–1732.

In addition, the heart is supplied with afferent nerve fibers, one set from the aortic arch called depressor fibers, the other set from the right side of the heart called pressor fibers. Both sets of afferent fibers run to the cardiac center in the medulla within the sheath of the vagi. Impulses over the depressor fibers bring about reflex inhibition of the heart. Impulses over the pressor fibers bring about reflex acceleration of the heart.

ARTERIES

The arteries are tubes that carry blood from the heart and break up into capillaries. They are composed of three coats: 1. An inner coat (*tunica intima*) consisting of three layers, — a layer of endothelial cells, a layer of delicate connective tissue, which is found only in vessels of considerable size, and an elastic layer consisting of a membrane or network of elastic fibers, in which, under the microscope, perforations may be seen. On this account it is sometimes called the *fenestrated membrane.*

2. A middle coat (*tunica media*) of muscular and elastic tissue. The muscular tissue consists of fine bundles of plain muscle fibers arranged in layers and circularly disposed around the vessel. In the large arteries elastic fibers form layers which alternate with the layers of muscle fibers. In the largest arteries a few bundles of white connective tissue have been found in this coat.

3. An external coat (*tunica adventitia*) of white connective tissue, which is dense. In all but the smallest arteries this coat contains some elastic tissue.

By virtue of the structure of the middle coat, the arteries are both extensile and elastic. The proper functioning of the arteries depends upon their extensibility and elasticity and may be demonstrated by the following example: if we tie a piece of a large artery at one end and inject fluid into the other end, the artery swells out to a very great extent, but will return at once to its former size when the fluid is let out.

The great extensibility and elasticity of the arteries adapt them for receiving the additional amount of blood forced into them at each contraction of the heart.

The strength of an artery depends largely upon the outer coat; it is far less easily cut or torn than the other coats, and serves to resist undue expansion of the vessel.

The arteries do not *collapse* when empty, and when an artery is severed, the orifice remains open. The muscular coat, however,

contracts somewhat in the neighborhood of the opening, and the elastic fibers cause the artery to retract a little within its sheath, so as to diminish its caliber and permit a blood-clot to plug the orifice. This property of the severed artery is an important factor in the arrest of hemorrhage.

The greater number of the arteries are accompanied by a nerve and one or two veins and surrounded by a **sheath** of connective tissue, which helps to support and hold these structures in position.

Size of the arteries. — The largest arteries in the body, the aorta and pulmonary artery, measure more than 3 cm. ($1\frac{1}{4}$ in.) in diameter, at their connection with the heart. These arteries give off branches, which divide and subdivide into smaller branches. The smallest arteries are called *arterioles*, and at their distal ends, where only the internal coat remains, the capillaries begin.

Blood supply of the arteries. — The blood which flows through the arteries nourishes only the inner coat. The external coat is supplied with arteries, capillaries, and veins, called **vasa vasorum** or blood-vessels of the blood-vessels.

CAPILLARIES

The capillaries are exceedingly minute vessels which average about 8 μ (0.008 mm.) in diameter. They connect the arterioles (smallest arteries) with the venules (smallest veins).

Structure. — The walls of the capillaries consist of one layer of endothelial cells continuous with the layer which lines the arteries, veins, and the heart.

Distribution. — The capillaries communicate freely with one another and form interlacing networks of variable form and size in the different tissues. All the tissues, with the exception of the cartilages, hair, nails, cuticle, and cornea of the eye, are traversed by these networks of capillary vessels. Their diameter is so small that the blood cells must pass through them in single file and very frequently the cell is larger than the caliber of the vessel, and has to be squeezed to enable it to pass through. In many parts they lie so closely together that a pin's point cannot be inserted between

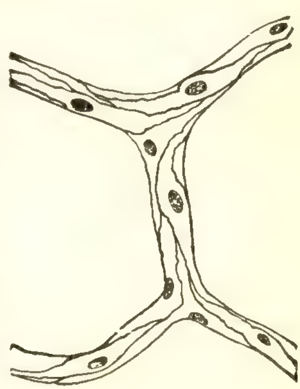


FIG. 148. — FINE CAPILLARIES FROM THE MESENTERY.

them. They are most abundant, and form the finest networks in those organs where the blood is needed for purposes other than local nutrition, as, for example, secretion or absorption.

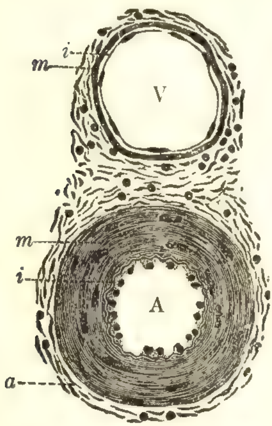


Fig. 149. — Transverse Section through a Small Artery and Vein, Showing the Relative Difference in the Thickness of Their Walls. *A*, artery showing *i*, the endothelial lining which with the thin layer of connective tissue and a layer of elastic fibers constitutes the *tunica intima*. The endothelial cells appear thick because the artery is contracted. The middle coat or *tunica media* consists of muscular and elastic tissue and constitutes the chief part of the vessel. Outside of this is *a*, part of the outer coat or *tunica adventitia*, which is dense, white, connective tissue. *V*, vein showing *i*, an inner endothelial membrane, and *m*, a middle muscular layer.

Function. — In the glandular organs the capillaries supply the substances requisite for secretion; in the ductless glands they take up the products of secretion; in the alimentary canal they take up some of the elements of digested food; in the lungs they absorb oxygen and give up carbon dioxide; in the kidneys they discharge the waste products collected from other parts; all the time, everywhere through their walls, that interchange is going on which is essential to the renovation and life of the whole body. It is in the capillaries, ~~then~~, that the chief work of the blood is done; ~~and the object of~~ the vascular ~~mechanism~~ is ~~to cause~~ the blood to flow through these vessels in a steady ~~stream~~.

VEINS

The veins are tubes that carry blood to the heart, and are made by the gathering together of the capillaries. The structure of the veins is similar to that of the arteries. They have three coats: (1) an inner endothelial lining, (2) a middle muscular layer, and (3) an external layer of connective tissue. The main differences between the veins and arteries are (1) the middle coat is not as well developed and not as elastic in the veins. (2) Many of the veins are provided with valves.

Valves. — The valves are semilunar folds of the internal coat of the veins, and usually consist of two flaps, rarely one or three. The convex border is attached to the side of the vein, and the free edge points toward the heart. Their function is to prevent reflux of the blood and keep it flowing in the right direction, ~~i.e.,~~ toward the heart.

If for any reason the blood on its onward course toward the heart is driven backward, the refluent blood, getting between the wall of the vein and the flaps of the valve, will press them inward until their edges meet in the middle of the channel and close it. The valves are most numerous in the veins where reflux is most likely to occur, *i.e.*, the veins of the extremities. For the same reason a greater number are found in the lower than in the upper limbs. They are absent in many of the small veins, in the large veins of the trunk, and in veins not subjected to muscular pressure. The veins, like the arteries, are supplied with blood-vessels; the supply, however, is far less abundant.

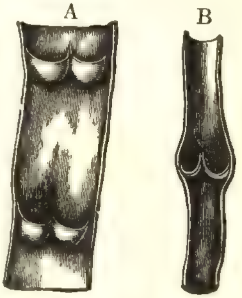


FIG. 150. — DIAGRAM SHOWING VALVES OF VEINS. *A*, part of a vein, laid open, with two pairs of valves; *B*, longitudinal section of vein, showing valves closed.

It must be remembered that although the arteries, capillaries, and veins have each the distinctive structure described, it is difficult to draw the line between the arteriole and large capillary; and between the large capillary and venule. The veins on leaving the capillary networks only gradually assume their several coats, while the arteries dispense with their coats in the same imperceptible way as they approach the capillaries.

Vasomotor nerves. — The muscular tissue in the walls of the blood-vessels is well supplied with nerve fibers, chiefly from the sympathetic portion of the autonomic system. These nerves are called **vasomotor** and are divided into two sets: (1) vasoconstrictor and (2) vasodilator. They connect with the vasoconstrictor center in the medulla oblongata, which is constantly sending impulses to the vessels, thus keeping them in a state of tone. The vasoconstrictor center is a reflex center, and is connected with afferent fibers coming from all parts of the body. Arteries are supplied with vasodilator fibers, which, when stimulated, inhibit the action of the vasoconstrictors and cause dilatation of the vessels. The widening and narrowing of the arteries not only affect the local circulation in different parts of the body, but the amount of resistance they oppose to the arterial impulse also influences in some degree the character of the heart beat.

SUMMARY

Blood Vascular System
- Heart.
- Arteries — small arteries are named arterioles.
- Capillaries.
- Veins — small veins are named venules.

A. **HEART**

- 1 **Location**
  - a Between lungs.
  - b Above diaphragm.
- 2 **Structure**
  - Outside covering — *Pericardium*
    - Fibrous portion.
    - Serous
      - Visceral.
      - Parietal.
  - a Muscle substance — *Myocardium*
    - Muscle bundles of the atria.
    - 1 Muscle bundles of the ventricles.
    - 2 **Atrioventricular bundle.** — Bundle of muscular and nervous tissue located in septum between right and left heart, which connects the musculature of atria and ventricles.
  - b Smooth lining on inside — *Endocardium.*
- 3 **Cavities**
  - a **Right heart**
    - 1 **Right atrium**
      - Receives blood.
      - Thin walls.
    - 2 **Right ventricle**
      - Expels blood into pulmonary artery.
      - Thick walls.
  - b **Left heart**
    - 1 **Left atrium**
      - Receives blood.
      - Thin walls.
    - 2 **Left ventricle**
      - Expels blood into aorta.
      - Very thick walls.
- 4 **Orifices**
  - a **Right heart**
    - 1 **Right atrium**
      - a Superior vena cava — returns blood from upper portion of body.
      - b Inferior vena cava — returns blood from lower portion of body.
    - c Atrioventricular orifice between atrium and ventricle.
    - 2 **Right ventricle**
      - a Pulmonary artery — carries blood from heart to lungs.
  - b **Left heart**
    - 1 **Left atrium**
      - b Two right pulmonary veins / Two left pulmonary veins — Return blood from lungs.
    - Atrioventricular orifice between atrium and ventricle.
    - 2 **Left ventricle**
      - Aorta — distributes blood to all parts of the body.
- 5 **Valves**
  - a **Tricuspid valve** — composed of three cusps situated in the right ventricle.
  - b **Bicuspid or mitral valve** — composed of two strong, thick cusps situated in the left ventricle.
  - c **Function** — Prevent flow of blood from ventricles into atria.

- **HEART**
  - **Valves**
    - **Semilunar valves**
      - **Aortic** — composed of three half-moon-shaped pockets between aorta and left ventricle.
      - **Pulmonary** — composed of three half-moon-shaped pockets between pulmonary artery and right ventricle.
      - **Function** — Prevent flow of blood from arteries into ventricles.
  - **Blood Supply**
    - **Arteries** — Right coronary, Left coronary — branches from aorta.
    - **Veins**
      1. Empty into coronary sinus.
      2. 3 or 4 small veins empty into right atrium.
      3. Veins of Thebesius empty into atrium and ventricles.
  - **Nerve Supply**
    - **Craniosacral system** — Vagi nerves, *inhibitory fibers*, slow the heart.
    - **Thoracolumbar system** — *Accelerator fibers* increase rapidity and force of heart.
    - **Afferent fibers**
      - Depressor — *reflex inhibitory.*
      - Pressor — *reflex accelerator.*

- **Arteries** — Characterized by elasticity
  - **Hollow tubes** — Carry blood *from* heart, break up into capillaries.
  - **Coats**
    1. Inner lining
       - ~~Layer of~~ endothelial cells.
       - Layer of connective ~~tissue~~.
       - Layer of elastic tissue — fenestrated membrane.
    2. Middle coat
       - Muscular and elastic tissue.
       - A few bundles of white connective tissue.
    3. External coat — White connective tissue with some elastic tissue.
  - **Sheaths** — outside covering of connective tissue which surrounds the arteries.
  - **Size** — Aorta more than one inch in diameter. Arteries grow smaller as they subdivide. Smallest ones are microscopic and are called **arterioles.**

- **Capillaries** — Characterized by multiplicity
  - ~~Tiny tubes — about 8 μ in diameter.~~ Connect arterioles and venules.
  - ~~One layer of endothelial cells.~~
  - ~~Communicate freely — form networks.~~

- **Veins** — Characterized by valves
  - **Collapsible tubes** — smallest ones, called venules, begin where capillaries end.
  - Carry blood to heart.
  - ~~Three~~ coats, same as arteries but thinner.
  - ~~Valves — semilunar pockets.~~

Vasa vasorum — The term applied to blood-vessels that are supplied to coats of other blood-vessels.

Vasomotor — Term applied to *nerve fibers* supplied to blood-vessels
- Vasoconstrictor.
- Vasodilator.

Turn to page 241 and

CHAPTER XIII

DIVISIONS OF THE VASCULAR SYSTEM: ARTERIES; VEINS; ACCESSORY OR PORTAL SYSTEM

The arteries which carry the blood from the heart to the capillaries are distributed throughout the body in a systematic manner. The vessels leaving the heart are large. They soon divide into smaller ones. This division continues until small branches are distributed to all parts of the body.

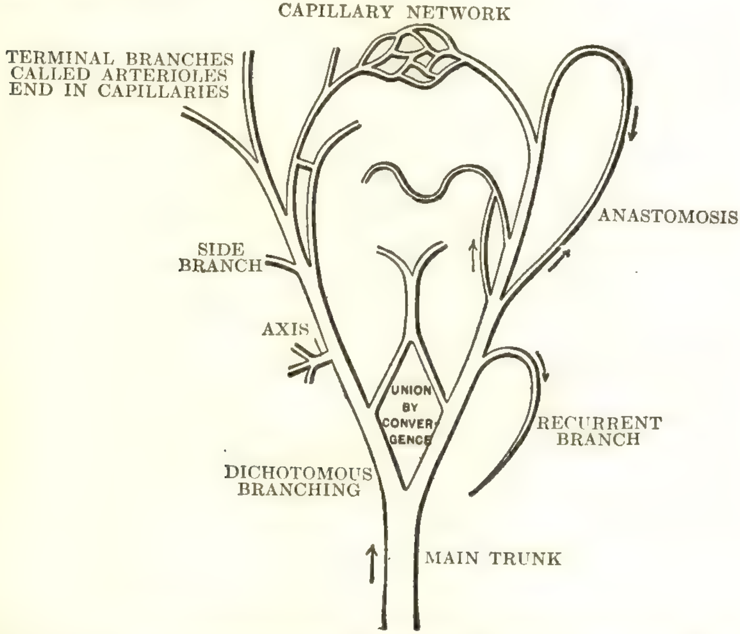


FIG. 151. — DIAGRAM SHOWING THE BRANCHING, ANASTOMOSES, AND CONFLUENCE OF ARTERIES. (Gerrish.)

Division. — The way in which the arteries divide varies. (1) An artery may give off several branches in succession and still continue as a main trunk, *e.g.*, the thoracic or abdominal portion of the aorta. (2) A short trunk may subdivide into several branches at the same point, *e.g.*, the celiac artery. (3) An artery may divide into two branches [1] of nearly equal size, *e.g.*, the division of the aorta into the two common iliacs.

[1] This is called dichotomous division.

Anastomosis or inosculation. — The distal ends of arteries unite at frequent intervals, when they are said to anastomose, or inosculate. Such inosculations admit of free communication between

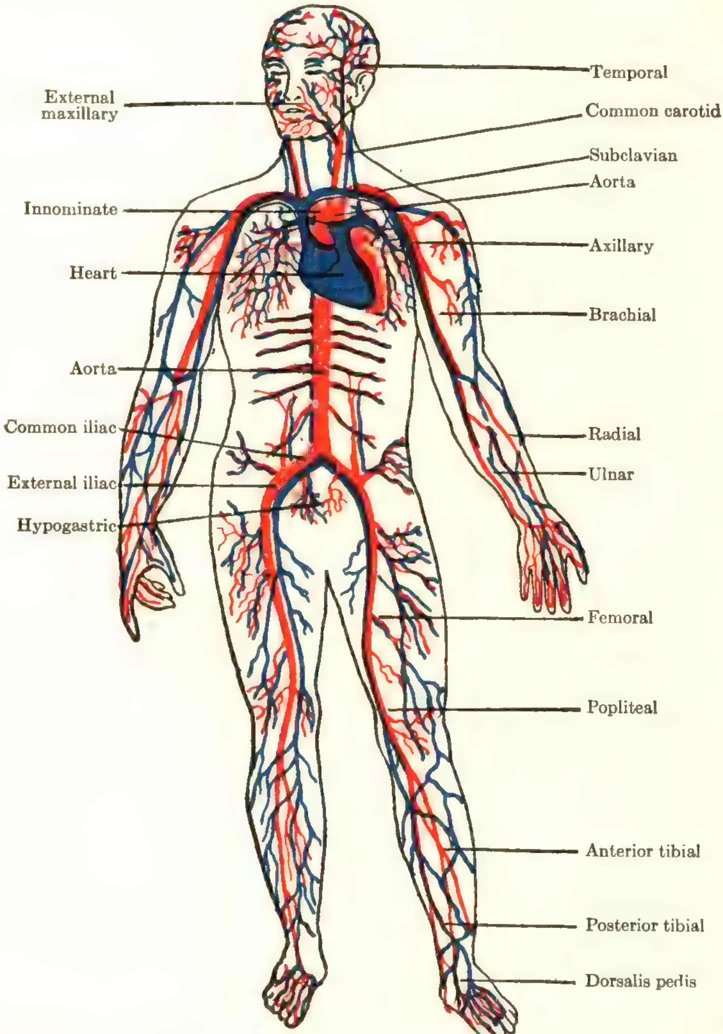


FIG. 152. — A GENERAL DIAGRAM OF THE CIRCULATION. MANY ARTERIES ARE NAMED.

the currents of the blood, tend to obviate the effects of local interruption, and promote equality of distribution and of pressure. Anastomoses occur between the larger as well as the smaller arteries.

Where great activity of the circulation is necessary, as in the brain, two branches of equal size unite, *e.g.*, the two vertebral arteries unite to form the basilar. (See Fig. 160.) In the abdomen, the intestinal arteries have frequent anastomoses between their larger branches. In the limbs, anastomoses are most numerous around the joints, the branches of the arteries above uniting with branches from the arteries below.

Anastomoses are of importance to the surgeon. By their enlargement, a collateral circulation is established, after an artery is ligated.

A *plexus* or network is formed by the inosculations of a number of arteries in a limited area. Arteries usually occupy *protected* situations, that they may be exposed as little as possible to accidental injury or to the effects of local pressure. Arteries usually pursue a fairly straight course, but in some parts of the body they are tortuous. The external maxillary (facial) artery, both in the neck and on the face, and the arteries of the lips (inferior and superior labial) are extremely tortuous, so that they may accommodate themselves to the movements of the parts.

DIVISIONS OF THE VASCULAR SYSTEM

The blood-vessels of the body are arranged in two main systems: 1. *The pulmonary*, which is the lesser system, provides for the circulation of the blood from the right ventricle to the lungs and back to the left atrium. 2. *The systemic*, which is the larger system, provides for the circulation of the blood from the left ventricle to all parts of the body by means of the aorta and its branches and the return to the right atrium by means of the venæ cavæ.

Blood-vessels of the pulmonary system. — The blood-vessels of the pulmonary systems are (1) the pulmonary artery and all its branches, (2) the capillaries which connect these branches with the veins, and (3) the pulmonary veins.

The pulmonary artery conveys venous blood from the right ventricle to the lungs. The main trunk is a short, wide vessel about 5 cm. (2 in.) in length and a little more than 3 cm. ($1\frac{1}{4}$ in.) in width. It arises from the right ventricle and passes upward, backward, and to the left. About the level of the intervertebral disc, between the fifth and sixth thoracic vertebræ, it divides into two branches, the right and left pulmonary arteries, which pass to the right and left lungs. Before entering the lungs, each artery divides into two branches. After entering, the branches

divide and subdivide, grow smaller in size, and finally merge into capillaries which form a network upon the walls of the air cells. These capillaries unite, grow larger in size, and gradually assume the

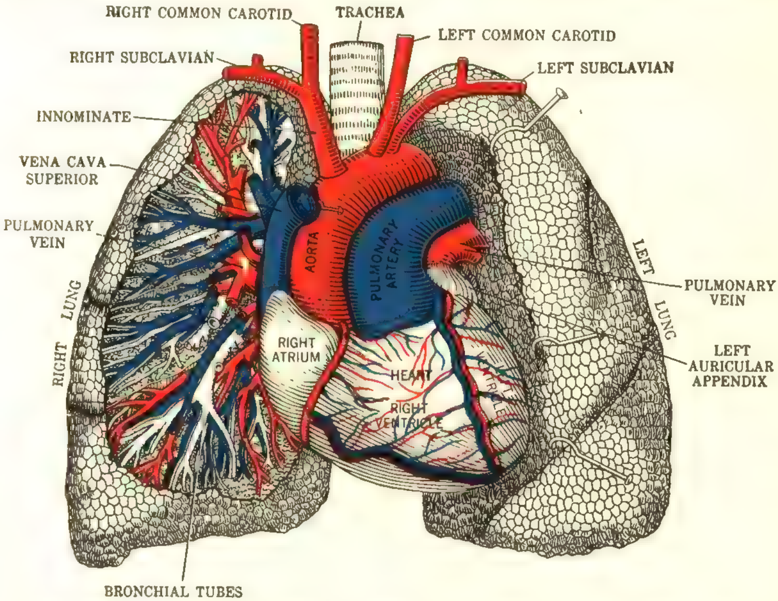


FIG. 153. — THE PULMONARY ARTERY AND AORTA. The front part of the right lung has been removed, and the pulmonary vessels and the bronchial tubes are thus exposed. (Gerrish.)

characteristics of veins. The veins unite to form the pulmonary veins.

The pulmonary veins are four short veins, two from each lung, which convey the blood from the lungs to the left atrium. They carry oxygenated blood to be distributed by the systemic arteries. The pulmonary veins have no valves.

Blood-vessels of the systemic system. — The blood-vessels of the general system consist of (1) the *aorta,* and all the arteries that originate from it, including the terminal branches called arterioles; (2) the capillaries which connect the arterioles and venules; (3) all the venules and veins of the body which empty into the superior and inferior venæ cavæ and then into the heart, as well as those which empty directly into the heart (coronary veins).

The aorta. — The aorta is the main trunk of the arterial system. Springing from the left ventricle of the heart, it arches over the

root of the left lung, descends along the vertebral column, and after passing through the diaphragm into the abdominal cavity, ends opposite the fourth lumbar vertebra by dividing into the right and left common iliac arteries. In this course the aorta forms a continuous trunk, which gradually diminishes in size from its commencement to its termination. It gives off large and small branches at various points.

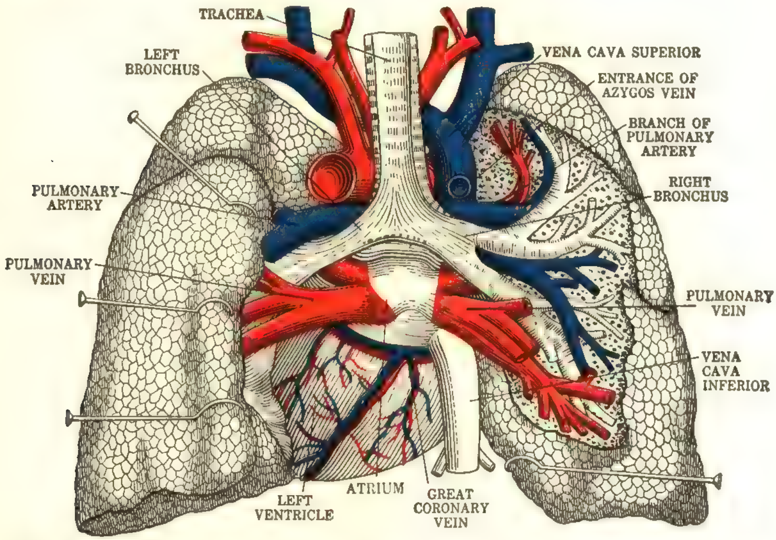


Fig. 154. — Pulmonary Vessels, Seen in a Dorsal View of the Heart and Lungs. The left lung is pulled to the left, and the right lung has been partly cut away to show the ramifications of the air tubes and blood-vessels.

It is divided into (1) the ascending aorta, (2) the arch, (3) the descending aorta, which is further subdivided into (*a*) the thoracic aorta and (*b*) the abdominal aorta.

(1) **The ascending aorta** is short, about 5 cm. (2 in.) in length, and is contained within the pericardium. The only branches of the ascending aorta are the right and left coronary, which have been described.

(2) **The arch** extends from the ascending aorta upward, backward, and to the left in front of the trachea, then backward and downward on the left side of the body of the fourth thoracic vertebra, where it becomes continuous with the descending aorta. Three branches are given off from the arch of the aorta — the *innominate*, the *left common carotid*, and the *left subclavian* arteries. Branches of these arteries supply the head and the upper extremities.

The innominate (brachiocephalic) artery arises from the right upper surface of the arch, ascends obliquely toward the right, until, arriving on a level with the upper margin of the clavicle, it divides into the right common carotid and right subclavian arteries.

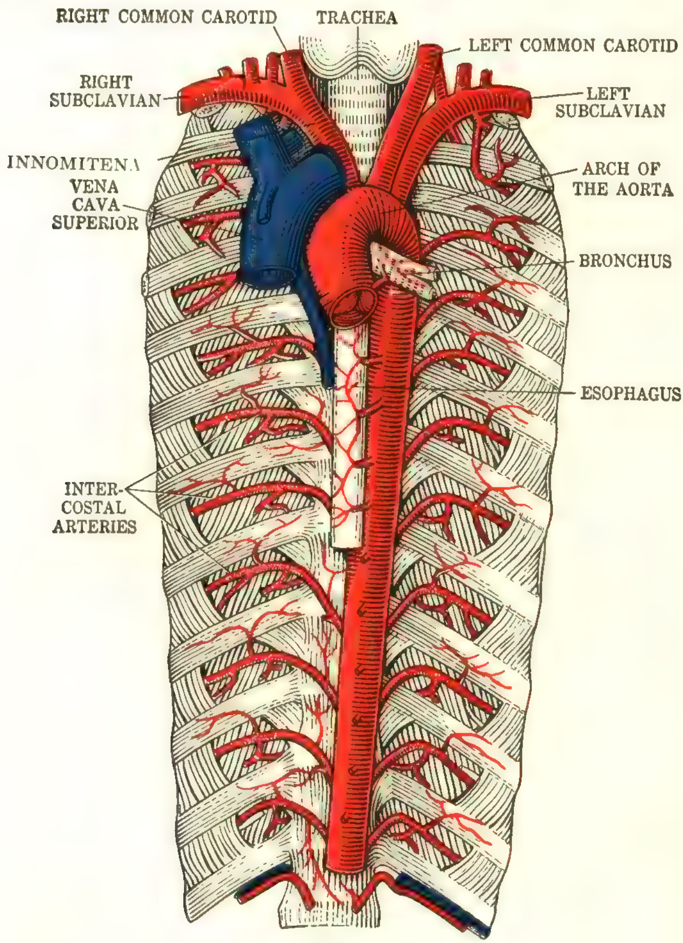


FIG. 155. — THORACIC AORTA.

(*a*) **The thoracic aorta** is the comparatively straight part that extends from the lower border of the fourth thoracic vertebra on the left side, to the aortic opening in the diaphragm in front of the lower border of the last thoracic vertebra. Branches from the thoracic aorta supply the body-wall of the chest cavity and the viscera which it contains.

(*b*) **The abdominal aorta** commences at the aortic opening of the diaphragm, in front of the lower border of the last thoracic vertebra, and terminates below by dividing into the two common iliac

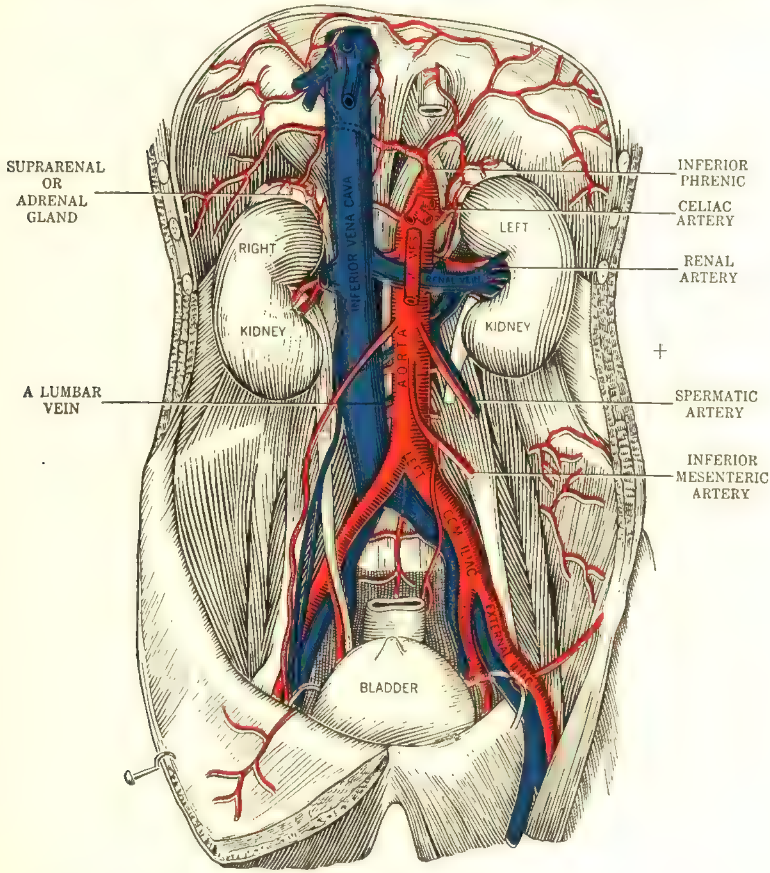


FIG. 156. — THE ABDOMINAL AORTA AND INFERIOR VENA CAVA.

arteries. The bifurcation usually takes place about halfway down the body of the fourth lumbar vertebra, which corresponds to a spot on the front of the abdomen, slightly below and to the left of the umbilicus. Branches from the abdominal aorta supply the body-wall of the abdominal cavity and the viscera which it contains.

ARTERIES OF THE TRUNK

Arteries of the chest. — The branches derived from the thoracic aorta are numerous but small, and the consequent decrease in size is not marked. They may be divided into two sets, (*a*) the visceral

or those which supply the viscera, and (*b*) the parietal or those which supply the walls of the chest cavity.

Visceral Group	Parietal Group
Pericardial arteries	Intercostal arteries
Bronchial arteries	Subcostal arteries
Esophageal arteries	Superior phrenic arteries
Mediastinal arteries	

The pericardial arteries are small and are distributed to the pericardium.

The bronchial arteries are the nutrient vessels of the lungs. They vary in number, size, and origin. As a rule, there are two left bronchial arteries, which arise from the thoracic aorta, and one right bronchial artery, which arises from the first aortic intercostal or from the upper left bronchial. Each vessel runs along the back part of the corresponding bronchus, dividing and subdividing along the bronchial tubes, supplying them and the cellular tissue of the lungs.

The esophageal arteries are four or five in number; they arise from the front of the aorta and form a chain of anastomoses along the esophagus. They anastomose with the esophageal branches of the thyroid arteries above, and with ascending branches from the left gastric and the left inferior phrenic arteries below.

The mediastinal arteries are numerous small arteries which supply the nodes and areolar tissue in the posterior mediastinum.

The intercostal arteries are usually nine in number on each side; they arise from the back of the aorta and are distributed to the lower nine intercostal spaces. Each intercostal artery is accompanied by a vein and a nerve; and each one gives off numerous branches to the muscles and skin. (See Fig. 155.)

The subcostal arteries lie below the last ribs and are the lowest pair of branches derived from the thoracic aorta.

The superior phrenic arteries are small. They arise from the lower part of the thoracic aorta, and are distributed to the posterior part of the upper surface of the diaphragm.

Arteries of the abdomen. — The branches derived from the abdominal aorta may be subdivided into two groups.

Visceral Branches	Parietal Branches
Celiac (celiac axis)	Inferior Phrenics
Superior Mesenteric	Lumbars
Middle Suprarenals	Middle Sacral
Renals	
Internal Spermatics (male), Ovarian (female)	
Inferior Mesenteric	

The celiac artery is a short, wide vessel, usually not more than 1.25 cm. ($\frac{1}{2}$ in.) in length, which arises from the front of the aorta just below the opening in the diaphragm. It divides into three branches: the *left gastric*, the *hepatic*, and the *splenic* or *lienal.*

The Left Gastric courses along the lesser curvature of the stomach from left to right, distributing branches to both surfaces. It anastomoses with the esophageal arteries at one end of its course and with the right gastric artery at the other.

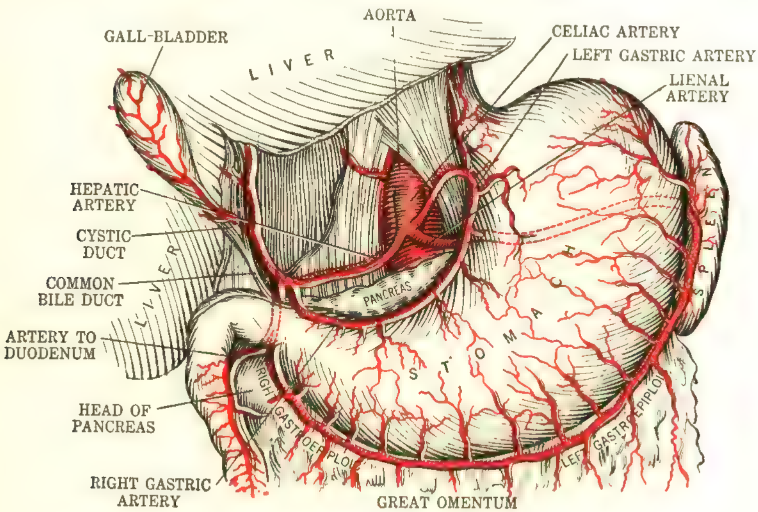


FIG. 157. — THE CELIAC ARTERY AND ITS BRANCHES. (Morris.)

The Hepatic Artery is the nutrient vessel of the liver. It gives off three branches: (*a*) the *right gastric*, which courses from right to left along the lesser curvature of the stomach and anastomoses with the left gastric; (*b*) the *gastroduodenal*, which splits into two vessels, one (superior pancreaticoduodenal) supplying the duodenum and the head of the pancreas, the other (right gastroepiploic) courses from right to left along the greater curvature of the stomach, distributes branches to it, and anastomoses with a branch of the splenic artery; (*c*) the cystic artery supplies the gall-bladder. Before entering the liver, the hepatic artery divides into two branches, right and left, which supply the corresponding lobes of the liver.

The Splenic or Lienal Artery is the largest of the three branches of the celiac. It distributes numerous vessels to the pancreas, several small and one large vessel — the left gastroepiploic — to the stomach. The left gastroepiploic runs along the greater

curvature of the stomach from left to right and anastomoses with the right gastroepiploic.

The superior mesenteric artery arises from the front part of the aorta, a little below the celiac artery. It supplies all of the small

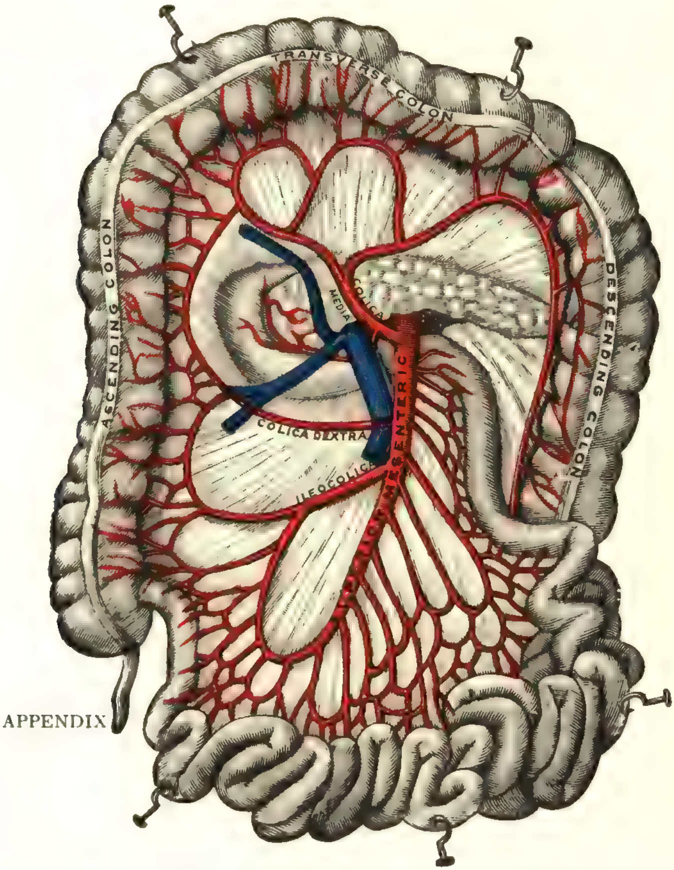


FIG. 158. — SUPERIOR MESENTERIC ARTERY.

intestine except the duodenum. It also supplies the cecum, the ascending colon, and half of the transverse colon. (See Fig. 158.)

The middle suprarenal arteries are of small size. They arise from the side of the aorta and pass to the suprarenal or adrenal glands, where they anastomose with branches of the phrenic and renal arteries.

The renal arteries, right and left, arise from the sides of the aorta, below the superior mesenteric artery. The right is generally

a little lower than the left. Each is directed outward, so as to form nearly a right angle with the aorta, and each divides into four or five branches before reaching the hilum of the kidney. (See Fig. 156.)

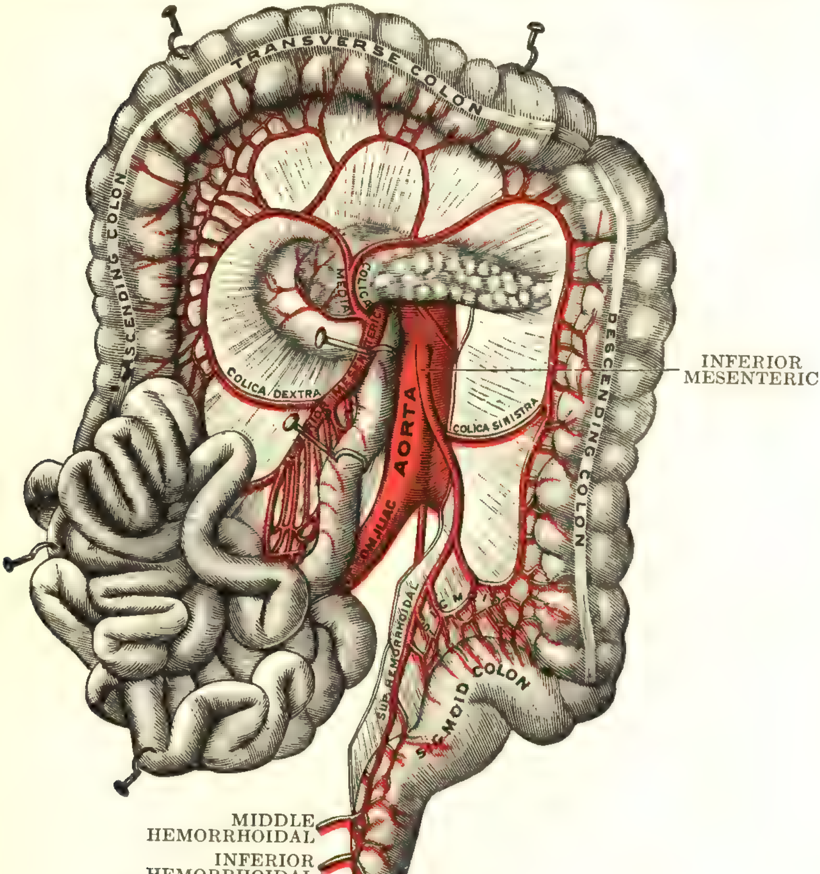


FIG. 159. — INFERIOR MESENTERIC ARTERY. (Gerrish.)

The internal spermatic arteries arise from the front of the aorta, a little below the renal arteries. They supply the testes. (See Fig. 156.)

The ovarian arteries in the female arise from the same portion of the aorta as the spermatic arteries in the male. They supply the ovaries and send small branches to the ureters and uterine tubes. One branch unites with the uterine artery (a branch of the hypogastric) and assists in supplying the uterus. During pregnancy the ovarian arteries become considerably enlarged.

The inferior mesenteric artery arises from in front of the aorta about 3.8 cm. ($1\frac{1}{2}$ in.) above the division of the aorta into the common iliacs. It distributes branches to the left half of the transverse colon and to the whole of the descending and sigmoid colon; continued under the name of the superior hemorrhoidal artery, it also takes part in the blood supply of the rectum.

The inferior phrenic arteries (two) may arise separately, or by a common trunk, from the aorta or celiac artery. They are distributed to the under surface of the diaphragm.

The lumbar arteries, usually four in number on each side, are analogous to the intercostals. They arise from the back of the aorta opposite the bodies of the upper four lumbar vertebræ. Occasionally a fifth pair arises from the middle sacral artery. These arteries distribute branches to the muscles and skin of the back; a spinal branch enters the vertebral canal and is distributed to the spinal cord and its membranes, also to the lumbar vertebræ.

The middle sacral artery arises from the back part of the abdominal aorta and passes down in front of the fourth and fifth lumbar vertebræ, the sacrum, and the coccyx to the coccygeal gland.[2]

Arteries of the pelvis. — When the descending aorta reaches the body of the fourth lumbar vertebra, it divides into the two **common iliac** arteries. These arteries pass downward and outward for about 5 cm. (2 in.), and then each divides into the hypogastric or internal and the external iliac arteries.

The hypogastric or internal iliac arteries send branches to the pelvic walls, pelvic viscera, the external genitals, the buttocks, and the medial side of each thigh. The uterine arteries in the female, which supply the tissues of the uterus with blood, are very important branches of the hypogastrics.

The external iliacs are placed within the abdomen, and extend from the bifurcation of the common iliacs to a point half way between the anterior superior spines of the ilia and the symphysis pubis.

The external iliacs send small branches to the psoas major muscles and to the neighboring lymph-nodes, and each gives off the *inferior epigastric* and the *deep iliac circumflex.* These arteries are of considerable size, and distribute branches to the abdominal muscles and peritoneum, also to the region of the pubes.

[2] The coccygeal gland consists of irregular masses of round or polyhedral cells, and is placed in front, or just below, the coccyx.

ARTERIES OF THE HEAD AND NECK

The principal arteries of the head and neck are the two common carotids.

The left common carotid arises from the middle of the upper surface of the arch of the aorta, and the right common carotid arises at the division of the innominate, consequently the left carotid is an inch or two longer than the right. They ascend obliquely on either side of the neck until, on a level with the upper border of the thyroid cartilage (Adam's Apple), they divide into two great branches: (1) the external carotid, (2) the internal carotid. At the root of the neck the common carotids are separated from each other by only a narrow interval, corresponding to the width of the trachea; but at the upper part, the thyroid gland, the larynx, and pharynx project forward between them.

The external carotid is the more superficial and is placed nearer the middle line than the internal carotid. Each external carotid has nine branches, which in turn break up into smaller branches. These supply the thyroid gland, the tongue, throat, face, ears, and the meningeal branches pass inside the cranium to the dura mater.

Each internal carotid has many branches, which are distributed to the brain, the eye and its appendages, the forehead, and the nose. Important branches are the cerebral, distributed to the brain, and the ophthalmic, which enters the orbital cavity through the optic foramen and distributes branches to the orbit, the muscles, and the bulb of the eye.

Circle of Willis.[3] — This is an arterial anastomosis at the base of the brain. It is formed by the union of the *anterior cerebral arteries*, which are branches of the internal carotid, and the *posterior cerebral arteries*, which are branches of the basilar. The *basilar* is formed by the union of the two *vertebrals*, which are branches of the subclavian.

The vertebrals ascend on either side of the vertebral column, pass through the foramen magnum, and at the base of the brain unite, to form the basilar artery. The basilar artery extends from the lower to the upper border of the pons Varoli, lying in the median groove. It ends by dividing into the two posterior cerebral arteries. These two arteries are connected on either side with the internal carotid by the posterior communicating arteries. In front, the anterior cerebral arteries are connected by the anterior communicating arteries. These arteries form a complete circle. (See

[3] Thomas Willis, English anatomist, 1621–1675.

Fig. 160.) This arrangement (1) equalizes the circulation of the blood in the brain, and (2) in case of destruction of one of the arteries, provides for the blood reaching the brain through other vessels.

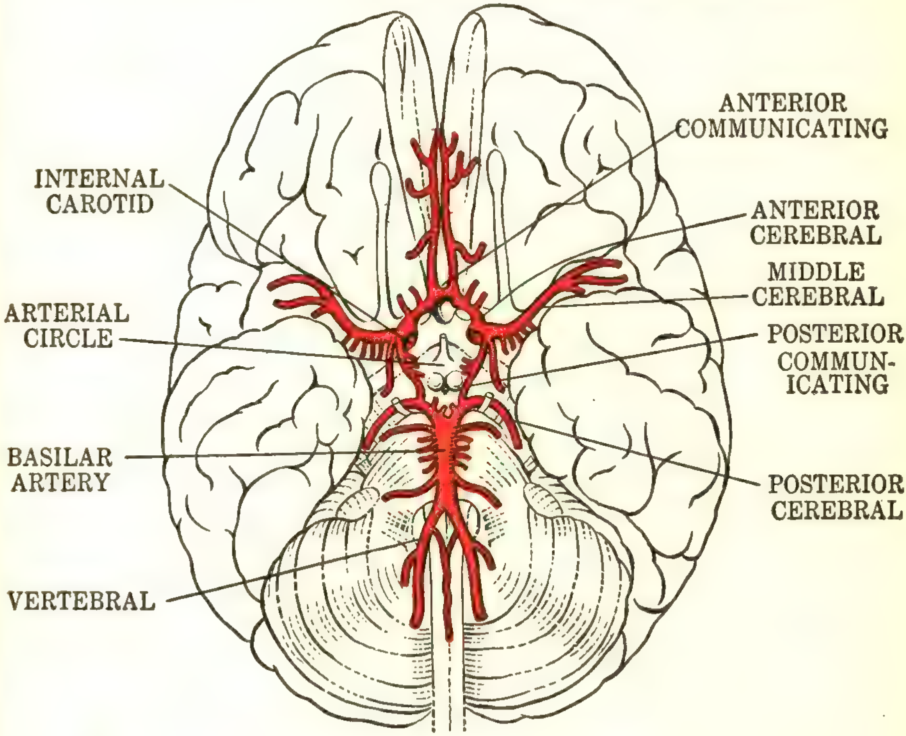


FIG. 160. — DIAGRAM OF THE ARTERIAL CIRCULATION AT THE BASE OF THE BRAIN showing the arterial circle of Willis. From this circle the anterior, middle, and posterior cerebral arteries extend to each cerebral hemisphere.

ARTERIES OF THE UPPER EXTREMITIES

The subclavian artery is the first portion of a long trunk which forms the main artery of each upper limb. Different portions are given different names, according to the regions through which it passes, *viz.*, subclavian, axillary, brachial, and at the elbow it divides into the radial and ulnar.

The right subclavian arises at the division of the innominate, and the left subclavian from the arch of the aorta. They pass a short way up into the neck, and then turn downward to rest on the first ribs. At the outer border of the first ribs they cease to be called subclavian and are continued as the axillaries. While these arteries

continue as the main arteries of the upper extremities, they distribute branches to the base of the brain, the chest, and shoulder regions.

(1) *The Vertebrals* have been described. See page 272

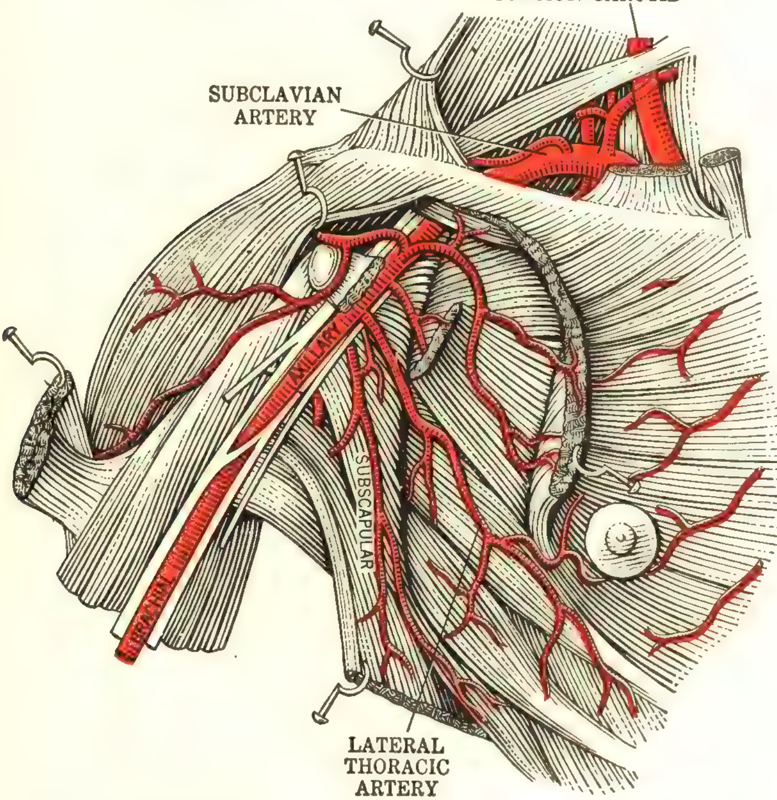


FIG. 161. — SUBCLAVIAN AND AXILLARY ARTERIES. (Gerrish.)

(2) *The Thyrocervical* sends branches to the thyroid, trachea, esophagus, muscles of the neck, and scapula.

(3) *The Internal Mammary* sends branches to the mammary glands,[4] the diaphragm, the areolar tissue, and lymph-nodes in the mediastinum, the intercostal muscles, the pericardium, and the abdominal muscles.

(4) *The Costocervical* sends branches to the upper part of the back, the neck, the spinal cord, and its membranes.

[4] The perforating branches of the internal mammary arteries are distributed to the mammary glands and are of large size during lactation.

(4) *The Costocervical* sends branches to the upper part of the back, the neck, the spinal cord, and its membranes.

The axillary artery (continuation of the subclavian) extends from the outer border of the first rib to the lower border of the

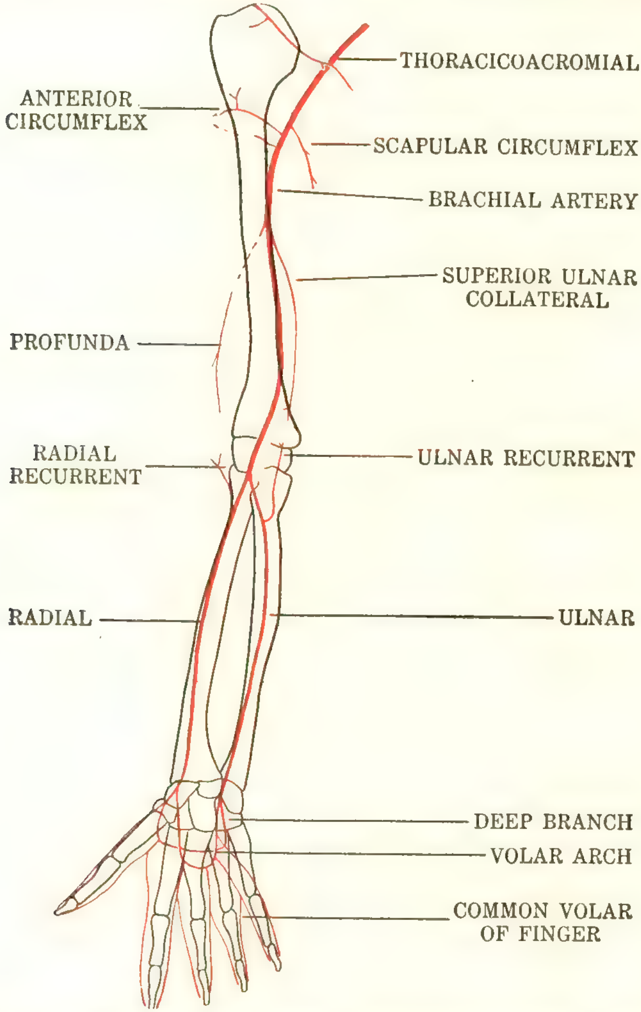


FIG. 162.—ANTERIOR VIEW OF THE ARTERIES OF THE ARM, FOREARM, AND HAND.

tendon of the teres major muscle where it becomes the brachial. Its direction varies with the position of the upper limb. At the beginning it is deeply situated, but near its termination it is superficial. It gives off branches to the chest. shoulder. and arm.

The brachial artery (continuation of the axillary) extends from the lower margin of the tendon of the teres major muscle to a short distance (1 cm.) below the elbow, where it divides into the radial and ulnar arteries. The upper part lies medial to the humerus, but as it passes down the arm it gradually gets in front of the bone and at the bend of the elbow it lies midway between its epicondyles. It may be located, lying in the depression along the inner border of the biceps muscle. Pressure made at this point from within outward against the humerus will control the blood supply to the arm.

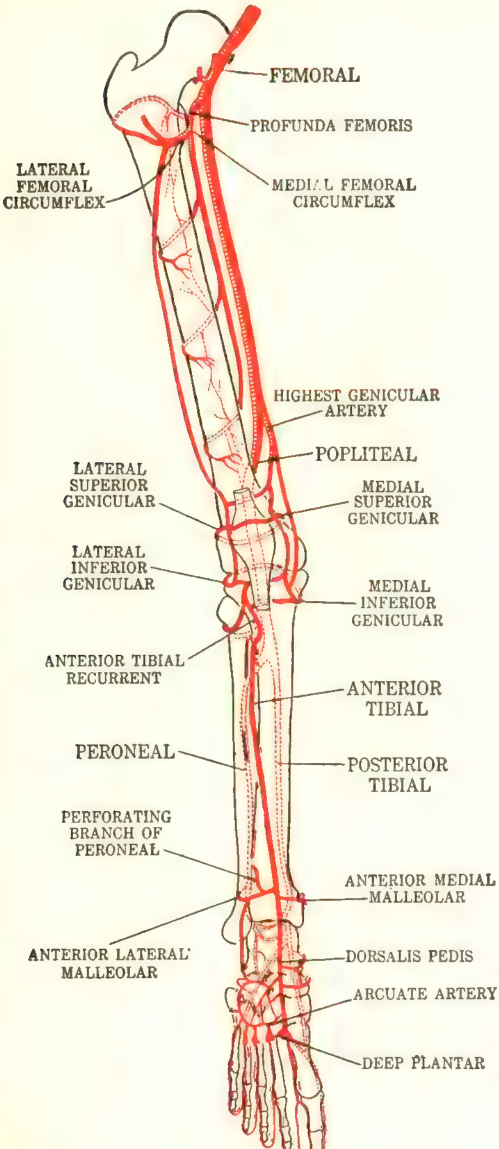


FIG. 163.—DIAGRAM OF ARTERIES OF THE LEG.

The ulnar, the larger of the two vessels into which the brachial divides, extends along the ulnar border of the forearm into the palm of the hand, where it divides into the branches which enter into the formation of the superficial and deep volar arches (palmar arches).

The radial artery appears, by its direction, to be a continuation of the brachial, although it does not equal the ulnar in size. It extends along the radial (thumb) side of the forearm as far as the

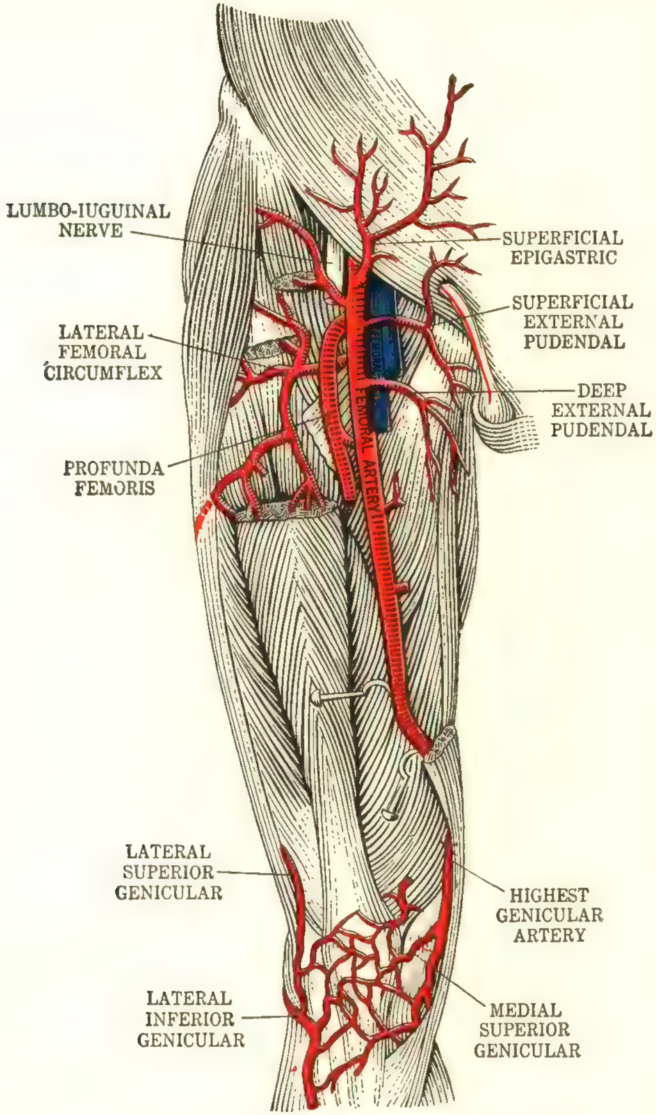


FIG. 164. — FEMORAL ARTERY. (Gerrish.)

lower end of the radius, below which it turns around the lateral side of the wrist, and passes forward into the palm of the hand, where it unites with the deep volar branch of the ulnar artery to form the deep volar arch. The superficial and deep volar arches anastomose and supply the hand with blood.

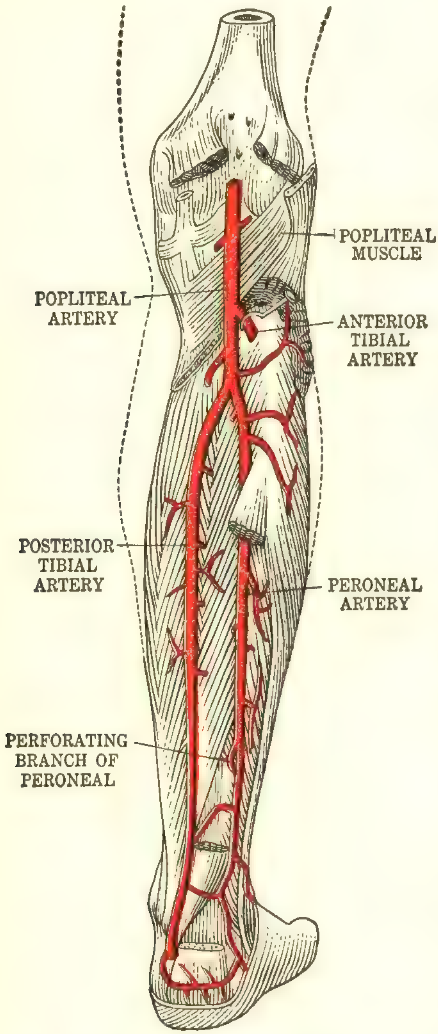


FIG. 165. — ARTERIES IN THE DORSAL PART OF THE LEG.

ARTERIES OF THE LOWER EXTREMITIES

The external iliac forms a large, continuous trunk, which extends downward in the lower limb, and is named in successive parts of its course, femoral, popliteal, and posterior tibial.

The femoral artery lies in the upper three-fourths of the thigh, its limits being marked above by the inguinal (Poupart's) ligament and below by the opening in the adductor magnus muscle. After passing through this opening the artery receives the name of popliteal. In the first part of its course the artery lies along the middle of the depression on the inner aspect of the thigh, known as the femoral triangle (Scarpa's triangle).[5] In this situation

[5] The femoral triangle (Scarpa's triangle) corresponds to the depression just below the fold of the groin. Its apex is directed downward. It is bounded above by the inguinal ligament, and the sides are formed laterally by the sartorius muscle and medially by the adductor longus.

Antonio Scarpa, Italian anatomist, 1747–1832.

the beating of the artery may be felt, and the circulation through the vessel may be most easily controlled by pressure. Branches from the femoral artery are distributed to the abdominal walls, the external genitals, the muscles and fasciæ of the thigh, and a descending branch, the *lateral femoral circumflex*, anastomoses with branches of the popliteal to form the *circumpatellar anastomosis* — which surrounds the knee joint.

The popliteal artery, a continuation of the femoral, is placed at the back of the knee. It sends branches to the knee joint, the posterior femoral muscles,[6] the gastrocnemius and soleus muscles, and to the skin of the back of the leg. Just below the knee joint it divides into the posterior tibial and anterior tibial arteries.

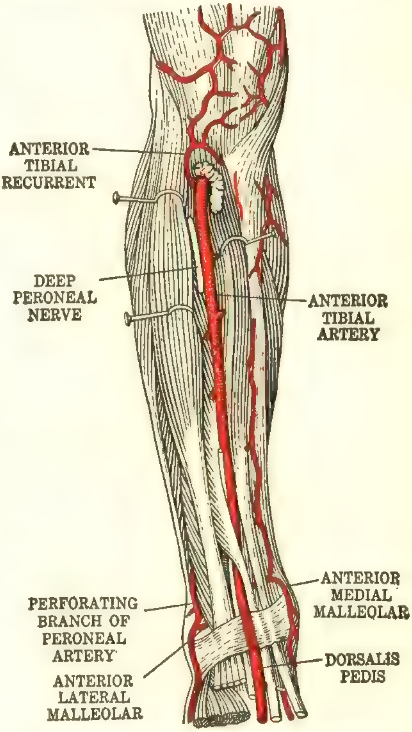


FIG. 166. — ANTERIOR TIBIAL ARTERY.

The posterior tibial artery lies along the back of the leg, and extends from the bifurcation of the popliteal to the ankle. It distributes branches to the calf of the leg and nutrient vessels to the tibia and fibula. At the ankle it divides into the *medial* and *lateral plantar* arteries, which supply the structures on the sole of the foot, form the plantar arch, and anastomose with branches from the dorsalis pedis.

The peroneal artery is a large branch given off by the posterior tibial just about 2.5 cm. (1 in.) below the bifurcation of the popliteal. The peroneal distributes blood to the structures on the medial side of the fibula and the calcaneus.

The anterior tibial artery, the smaller of the two divisions of the popliteal trunk, extends along the front of the leg to the front of the ankle joint and becomes the dorsalis pedis artery. The dorsalis pedis anastomoses with branches from the posterior tibial, and supplies blood to the foot.

[6] These are the biceps femoris, semitendinosus and semimembranosus.

VEINS

The arteries begin as large trunks, which gradually become smaller and smaller until they end in arterioles, which merge into capillaries, while the veins begin as small branches called venules which at first are scarcely distinguishable from the capillaries, and unite to form larger and larger vessels. They differ from the arteries in their larger size, greater number, thinner walls, and in the presence of valves which prevent backward circulation. They consist of two sets of vessels, the **pulmonary** and the **systemic.**

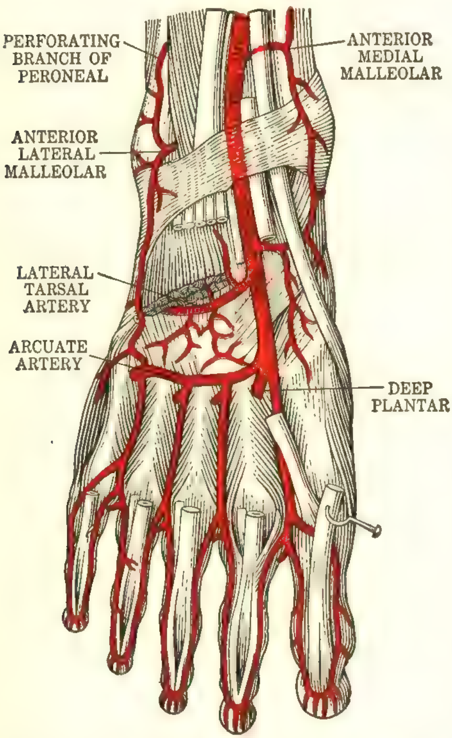


FIG. 167. — ARTERIES OF THE DORSUM OF THE FOOT. (Gerrish.)

The pulmonary veins convey oxygenated blood from the lungs to the left atrium. These veins commence in the capillary network upon the air cells, and unite to form one vein for each lobule. These further unite to form one vein for each lobe, two for the left lung and three for the right. The vein from the middle lobe of the right lung usually unites with that from the upper lobe, and finally two trunks from each lung are formed. They have no valves and open separately into the left atrium.

The systemic veins return the blood from all parts of the body to the right atrium of the heart. In other words, the blood distributed by the systemic arteries is returned by the systemic veins. The systemic veins are divided into three sets, — superficial, deep, and venous sinuses.

The Superficial Veins are found just beneath the skin in the superficial fascia, and return the blood from these structures. They are sometimes called cutaneous veins. The superficial and

deep veins unite very frequently. The anastomoses of veins are more numerous than those of arteries.

The Deep Veins accompany the arteries, and are usually enclosed in the same sheath. The deep veins accompanying the smaller arteries, such as the brachial, ulnar, radial, peroneal, and tibial, are found in pairs, one on each side of the vessel, and are called venæ comitantes or companion veins. Usually the larger arteries, such as the femoral, popliteal, axillary, and subclavian, have only one accompanying vein (vena comes).

In certain parts of the body the deep veins do not accompany the arteries. Examples are (1) the veins in the skull and the vertebral canal, (2) the hepatic veins in the liver, and (3) the larger veins which return blood from the bones.

The *Venous Sinuses* are canals found only in the interior of the skull. They are formed by a separation of the layers of the dura mater, the fibrous membrane which covers the brain. Their outer wall consists of the dura mater, and their inner lining of endothelium is continuous with the lining membrane of the vessels that communicate with them. (See Fig. 117.)

The systemic veins are divided into three groups: (1) veins that empty into the heart, (2) veins that empty into the superior vena cava, and (3) veins that empty into the inferior vena cava.

(1) Five of the veins of the heart empty into the right atrium by way of the coronary sinus. Some smaller veins empty directly into the atria and ventricles. (See page 253.)

(2) The veins of the head, neck, upper extremities, and thorax empty into the **superior vena cava,** which carries the blood to the right atrium.

(3) The veins of the lower extremities, of the abdomen and pelvis, empty into the **inferior vena cava,** which carries the blood to the right atrium.

VEINS OF THE NECK

The blood returning from the head and face flows on each side into two principal veins, the external and internal jugular.

The external jugular veins are the chief *superficial* veins of the neck. They are formed in the substance of the parotid glands by the union of the posterior facial and the posterior auricular veins of each side of the face. This union takes place on a level with the angle of the mandible and each vein descends almost vertically down the neck to its termination in the subclavian vein.

These two veins receive the blood from the deep parts of the face and the exterior of the cranium.

The internal jugular veins are continuous with the lateral sinuses, and begin in the jugular foramen at the base of the skull. They descend on either side of the neck, first with the external carotid, then with the common carotid, and join at a right angle with the subclavian to form the innominate (brachiocephalic) vein. They receive the blood from the veins and sinuses of the cranial cavity, the superficial parts of the face, and from the neck. In a general way the tributaries of the internal jugular veins correspond to the branches of the external carotid arteries. (See Fig. 170.)

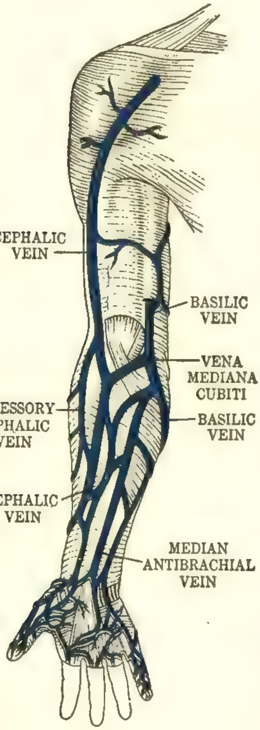


FIG. 168. — SUPERFICIAL VEINS OF THE FOREARM, ARM, AND HAND.

VEINS OF THE UPPER EXTREMITIES

The blood from the upper limbs is returned by a deep and a superficial set of veins. The deep veins are the venæ comitantes of the forearm and arm and are called by the same names as the arteries, *i.e.*, the deep volar venous arches, metacarpal veins, radial and ulnar veins, brachial veins, axillary veins, and subclavian veins. The deep veins have numerous anastomoses with one another and with the superficial veins.

The superficial veins are much larger than the deep, and take a greater share in returning the blood, especially from the distal portion of the limb. They commence in two plexuses, one on the back of the hand, formed by the dorsal metacarpal veins — the dorsal venous network, — and another plexus situated over the thenar and hypothenar eminences and across the front of the wrist. They include the following:

The cephalic vein begins in the dorsal network and winds upward around the radial border of the forearm, to a little below the bend of the elbow, where it joins the accessory cephalic vein to form the cephalic of the upper arm.

The basilic vein begins in the ulnar part of the dorsal network and extends upward along the posterior surface of the ulnar side, to a little below the elbow, where it is joined by the median basilic vein (*vena mediana cubiti*). It continues upward to the lower border of the teres major muscle.

The axillary vein is a continuation of the basilic in the upper arm. It ends at the outer border of the first rib, in the subclavian vein. It receives the brachial veins and close to its termination the cephalic vein. It also receives veins which correspond with the branches of the axillary artery.

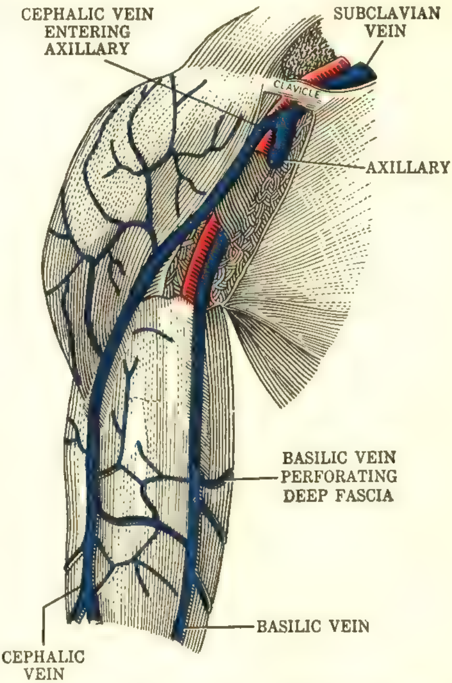


FIG. 169. — SUPERFICIAL VEINS OF FRONT OF ARM AND SHOULDER. (Gerrish.)

The subclavian vein is a continuation of the axillary extending from the first rib to the joint between the sternum and clavicle, where it unites with the internal jugular to form the innominate vein. At the junction with the internal jugular the left subclavian vein receives the thoracic duct, and the right subclavian vein receives the right lymphatic duct.

VEINS OF THE THORAX

On each side the **innominate vein** formed by the union of the subclavian and internal jugular veins receives the blood returning from the head, neck, mammary gland, and the upper part of the thorax. These veins transmit this blood to the superior vena cava.

The right innominate is about 2.5 cm. (1 in.) in length, and the left is about 6 cm. ($2\frac{1}{2}$ in.) in length.

The superior vena cava is formed by the union of the right and left innominate veins, just behind the junction of the first right

costal cartilage with the sternum. It is about 7.5 cm. (3 in.) long, and opens into the right atrium, opposite the third right costal cartilage.

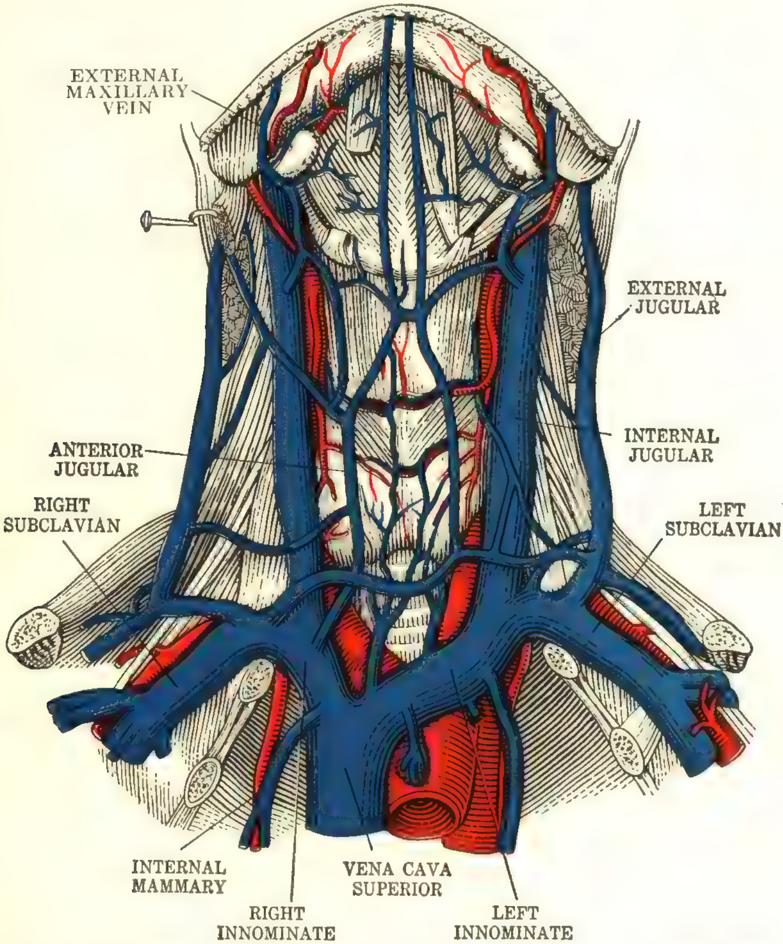


FIG. 170. — VEINS OF THE NECK AND UPPER PART OF THORAX. Front View. (Gerrish.)

Supplementary channel. — A supplementary channel between the inferior and superior venæ cavæ is formed by the azygos veins. In case of obstruction, these veins form a channel by which blood can be conveyed from the lower part of the body to the superior vena cava. They are three in number and lie on the right and left sides of the front of the vertebral column.

The azygos vein (right or major azygos) begins opposite the first or second lumbar vertebra as the *right ascending lumbar vein,*[7] or by a branch of the *right renal vein*, or from the *inferior vena cava.*

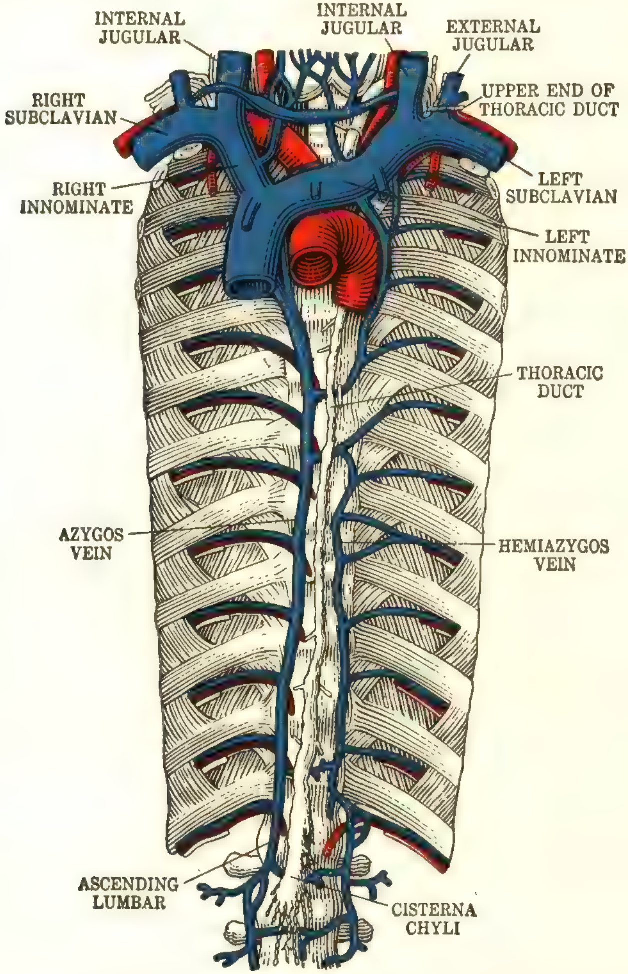


FIG. 171. — AZYGOS AND INTERCOSTAL VEINS, ALSO THORACIC DUCT. (Gerrish.)

It ascends on the right side of the vertebral column to the level of the fourth thoracic vertebra, where it arches over the root of the right lung and empties into the superior vena cava.

[7] The lumbar veins empty into the inferior vena cava. They correspond to the lumbar arteries given off by the abdominal aorta, and return the blood from the muscles and skin of the loins and walls of the abdomen.

The hemiazygos vein (left lower or minor azygos) begins in the left lumbar or renal vein. It ascends on the left side of the vertebral column, and at about the level of the ninth thoracic vertebra it connects with the right azygos vein. It receives the lower four or five intercostal veins of the left side and some esophageal and mediastinal veins.

The accessory hemiazygos vein (left upper azygos) connects above with the highest left intercostal vein, and opens below into either the azygos or the hemiazygos. It varies considerably in size, position, and arrangement. It receives veins from the three or four intercostal spaces between the highest left intercostal vein and highest tributary of the hemiazygos; the left bronchial vein sometimes opens into it.

The bronchial veins. — A bronchial vein is formed at the root of each lung and returns the blood from the larger bronchi, and from the structures at the root of the lung; that of the right side opens into the azygos vein, near its termination; that of the left side, into the highest left intercostal or the accessory hemiazygos vein. A considerable quantity of the blood which is carried to the lungs through the bronchial arteries is returned to the left side of the heart through the pulmonary veins.

VEINS OF THE LOWER EXTREMITIES

The blood from the lower limbs is returned by a superficial and a deep set of veins. The superficial veins are beneath the skin, between the layers of superficial fascia. The deep veins accompany the arteries. Both sets are provided with valves, which are more numerous in the deep than in the superficial veins.

The Superficial Veins of the lower extremities are the great saphenous, the small saphenous veins, and their tributaries. The superficial veins of the foot form venous arches on the dorsum and sole of the foot. These arches communicate with each other and receive branches from the deep veins. They drain the blood into a *medial* and *lateral* marginal vein.

The great saphenous vein begins in the medial marginal vein of the dorsum of the foot, extends upward on the medial side of the leg and thigh, and ends in the femoral vein a little more than 3 cm. ($1\frac{1}{4}$ in.) below the inguinal ligament. At the ankle it receives branches from the sole of the foot; in the leg it anastomoses with the small saphenous vein and receives many cutaneous veins. In the thigh it receives many branches. Those from the posterior

and medial aspects of the thigh frequently unite to form an accessory saphenous vein, which joins the great saphenous.

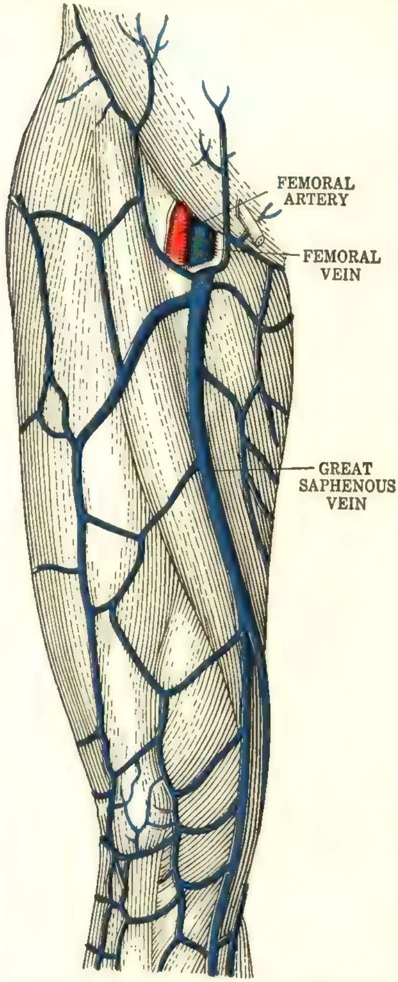


FIG. 172. — SUPERFICIAL VEINS OF THE FRONT OF THE RIGHT THIGH. (Gerrish.)

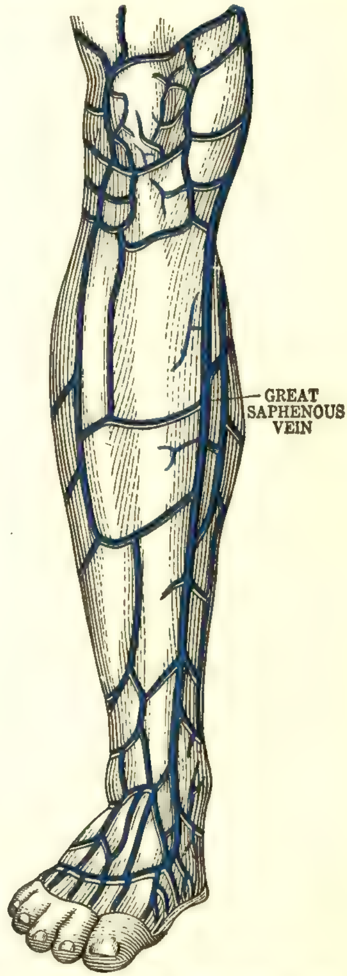


FIG. 173. — SUPERFICIAL VEINS OF THE FRONT OF THE LEG AND FOOT. (Gerrish.)

The small saphenous begins behind the lateral malleolus, as a continuation of the lateral marginal vein, and passes up the back of the leg to end in the deep popliteal vein. It receives many branches from the deep veins on the dorsum of the foot and from the back of the leg. Before it joins the popliteal, it gives off a branch that runs upward and forward and joins the great saphenous.

The Deep Veins accompany the arteries below the knee. They are in pairs and are called by the same names as the arteries. The veins from the foot empty into the *anterior tibial* and *posterior tibial veins.* They unite to form the single *popliteal* vein, which is continued as the *femoral* and becomes the *external iliac.*

FIG. 174. — SUPERFICIAL VEINS OF THE DORSUM OF THE LEG. (Gerrish.)

The femoral veins are continuations of the popliteal veins and extend from the opening in the adductor magnus muscles to the level of the inguinal ligament. Each one receives numerous branches and near its termination it is joined by the great saphenous vein.

VEINS OF THE ABDOMEN AND PELVIS

The external iliac veins are continuations of the femoral veins, and extend from the level of the inguinal (Poupart's) ligament, on either side, to the joint between the sacrum and the ilium.

The hypogastric veins are formed by the union of veins corresponding to the branches of the hypogastric arteries. They accompany the hypogastric arteries and unite with the external iliac veins to form the common iliacs. (See Fig. 156.)

The common iliacs extend from the base of the sacrum to the fifth lumbar vertebra, and then the two common iliacs unite to form the inferior vena cava. (See Fig. 156.)

The inferior vena cava begins at the junction of the two common iliacs, and thence ascends along the right side of the aorta, perforates the diaphragm, and terminates by entering the right atrium of the heart. The shape and position of the inferior vena cava is comparable to that of the abdominal aorta, and it returns blood from the parts below the diaphragm. It receives veins having the same names as the parietal and visceral branches of

the abdominal aorta. These veins are (1) lumbar, (2) renal, (3) suprarenal, (4) inferior phrenic, (5) hepatic, (6) right spermatic or ovarian. Most of these veins accompany the arteries and follow the same course.

There are a few exceptions.

(1) The right suprarenal vein empties into the inferior vena cava, the left empties into the left renal or left inferior phrenic.

(2) The right inferior phrenic empties into the inferior vena cava; the left often consists of two branches, one of which empties into the left renal or suprarenal vein, and the other into the inferior vena cava.

(3) The hepatic veins empty into the inferior vena cava, but they commence in the sinusoids of the liver.

(4) The right spermatic vein empties into the inferior vena cava, but the left empties into the left renal vein. The ovarian veins end in the same way as the spermatic veins in the male.

The veins that return the blood distributed by the branches of the celiac, the superior and inferior mesenteric, are included in the portal system.

The portal system. — The veins which bring back the blood from the spleen, stomach, pancreas, and intestines are included in the portal system. Blood is collected from the spleen by veins which unite to form the *splenic vein.* This vein passes back of the pancreas from left to right and ends by uniting with the *superior mesenteric,* to form the *portal tube.* Before this union takes place, the splenic receives *gastric veins, pancreatic veins,* and the *inferior mesenteric vein,* which returns the blood from the rectum, sigmoid, and descending colon. The *superior mesenteric vein* returns the blood from the small intestine, the cecum, the ascending and transverse portions of the colon.

The portal tube, formed at the level of the second lumbar vertebra by the union of the splenic and the superior mesenteric, passes upward and to the right to the transverse fissure of the liver. Here it divides into a right and a left branch, which accompany the right and left branches of the hepatic artery into the right and left lobes of the liver. Before entering the liver, the right branch usually receives the cystic vein, which returns blood from the gall-bladder. In the liver these veins accompany the arteries, and like them divide into capillary-like vessels, called *sinusoids.* These sinusoids unite with the capillaries from the hepatic artery to form the *hepatic veins,* which carry the blood brought to the liver by both the hepatic artery and the portal vein, to the inferior vena cava. Thus it will be seen that the liver receives blood from two sources: (1) the portal tube carries blood containing soluble materials such as simple sugars and amino-acids which have been absorbed from the digestive tract. These products are acted upon by

the liver cells before reaching the general circulation. (2) The hepatic artery carries oxygenated blood sent out from the left ventricle by way of the aorta and the celiac artery. This blood

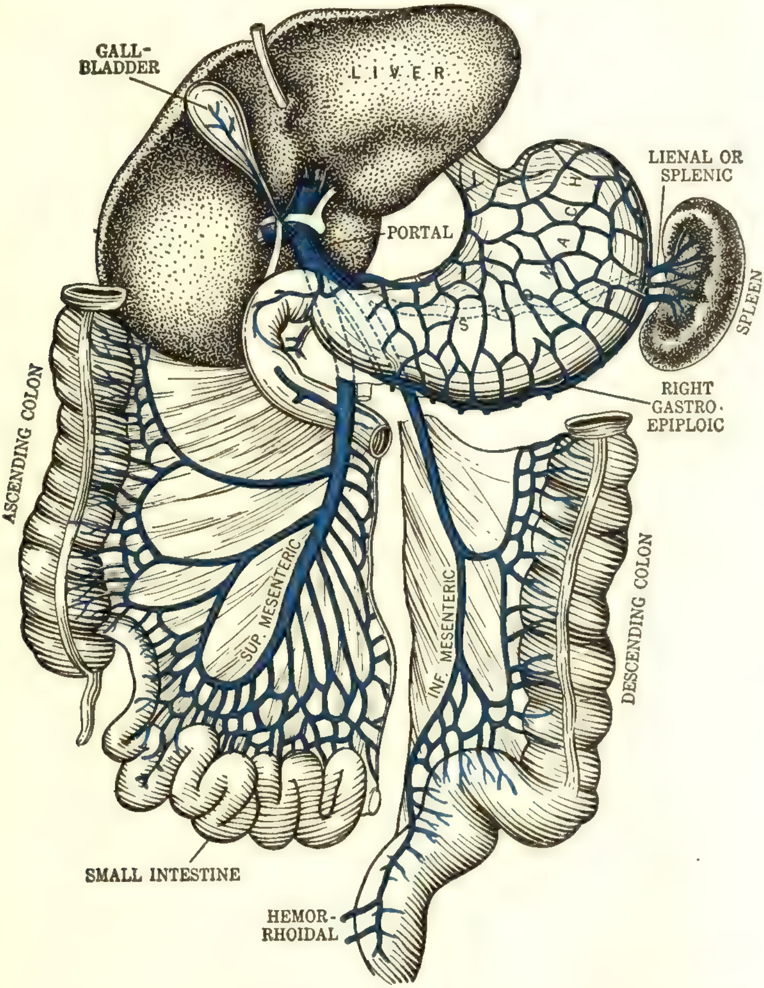


FIG. 175. — PORTAL SYSTEM OF VEINS. The liver is turned upward and backward, and the transverse colon and most of the small intestines are removed. (Gerrish.)

is for purposes of nourishment of the liver itself. The blood from both sources of supply is carried from the liver by the hepatic veins.

The portal tube and all its branches constitute the portal system, described as a third or accessory system.

SUMMARY

- **Arteries**
  - Begin as large trunks, grow smaller.
  - Usually deep seated for protection.
  - Division
    - Trunk gives off several branches.
    - One branch that divides into several.
    - Two branches of nearly equal size.
  - Anastomosis or inosculation — distal ends unite.
  - Plexus — many inosculations within limited area.
  - Usually straight (external maxillary, inferior and superior labial are tortuous).

- **Divisions of the Vascular System**
  - Pulmonary System
    - Provides for pulmonary circulation.
    - 1. Pulmonary artery conveys venous blood from right ventricle to lungs.
      - Right pulmonary artery — right lung.
      - Left pulmonary artery — left lung.
    - 2. Capillaries connect arterioles and venules.
    - 3. Four pulmonary veins — two from each lung — convey oxygenated blood to left atrium.
  - Systemic System
    - Provides for systemic circulation.
    - 1. Aorta and all its branches.
    - 2. Capillaries connect arterioles and venules.
    - 3. Veins empty into heart either directly or by means of inferior and superior venæ cavæ.

- **Aorta**
  - I Ascending Aorta
    - About 2 inches long.
    - Branches
      - Right coronary.
      - Left coronary.
  - II Arch of Aorta
    - Extends from ascending aorta to body of 4th thoracic vertebra.
    - Branches
      - Innominate
        - Right common carotid.
        - Right subclavian.
      - Left common carotid.
      - Left subclavian.
  - III Descending Aorta
    - Thoracic Aorta
      - Extends from lower border of 4th thoracic vertebra to aortic opening in diaphragm.
      - Branches supply body-wall and viscera of thorax.
    - Abdominal Aorta
      - Extends from aortic opening in diaphragm to body of 4th lumbar vertebra. Branches supply body-wall and viscera of abdominal cavity.

- **Arteries of the Chest**
  - Visceral Group
    - Pericardials — to pericardium.
    - Bronchials — nutrient vessels of lungs.
    - Esophageals — to esophagus.
    - Mediastinals — to nodes and areolar tissue in mediastinum.

- **Arteries of the chest**
  - Parietal Group
    - **Intercostals** — to lower nine intercostal spaces.
    - **Subcostals** — anastomose with superior epigastrics, lower intercostals and lumbar arteries.
    - **Superior phrenics** — upper surface of diaphragm.

- **Arteries of Abdomen Visceral branches**
  - Celiac Artery
    - **Left gastric** — lesser curvature of stomach — left to right.
    - **Hepatic artery** divides into right and left branches before entering liver.
      - **Right gastric** — lesser curvature of stomach — right to left.
      - Gastro-duodenal
        - *Superior pancreatico-duodenal* to duodenum and head of pancreas.
        - *Right gastroepiploic*— greater curvature of stomach —right to left.
      - **Cystic** — gall-bladder.
    - **Lienal or splenic**
      - Branches to pancreas.
      - **Left gastroepiploic** — greater curvature of stomach left to right.
  - **Superior Mesenteric** — Supplies small intestine except duodenum, cecum, ascending colon, half of transverse colon.
  - **Inferior Mesenteric** — Supplies left half transverse colon, whole of descending and sigmoid colon, continued as *superior hemorrhoidal* artery to rectum.
  - **Middle Suprarenals** — To suprarenal glands — anastomose with branches of phrenic and renal arteries.
  - **Renal Arteries** — Each divides into four or five branches before entering kidney.
  - **Internal Spermatics** — Supply the testes.
  - **Ovarian Arteries** — Supply ovaries, send small branches to the ureters and uterine tubes, one branch unites with uterine artery and assists in supplying uterus.

- **Arteries of Abdomen Parietal Branches**
  - **Inferior Phrenics** — distributed to under surface of diaphragm.
  - **Lumbar Arteries** — Distribute branches to muscles and skin of back, to the spinal cord and its membranes and to the lumbar vertebræ.
  - **Middle Sacral** — Passes down to coccygeal gland.

- **Arteries of the Pelvis**
  - **Common Iliacs** about 5 cm.
    - **Hypogastric or Internal iliacs** — Send branches to pelvic walls, pelvic viscera, external genitals, buttocks, medial side of thighs.
    - **External iliacs**
      - Send branches to psoas major muscles and neighboring nodes.
      - Inferior epigastric.
      - Deep iliac circumflex.

- **Arteries of Head and Face**
  - **Left Common Carotid arises from arch of aorta**
    - **External carotid**
      - Branches supply thyroid gland, tongue, throat, face, ear, and dura mater.
    - **Internal carotid**
      - Branches same as on right side
  - **Right Common Carotid arises at division of innominate**
    - **External carotid**
      - Branches same as on left side.
    - **Internal carotid**
      - Branches supply brain, eye and its appendages, forehead, and nose.
  - **Circle of Willis**
    - Anastomosis at base of brain.
    - Formed by union of
      - Anterior cerebral arteries connected by anterior communicating arteries.
      - Posterior cerebral arteries connected by posterior communicating arteries.
- **Arteries of the Upper Extremities**
  - **Subclavian** — forms main artery of each upper limb. Different portions named according to regions through which it passes.
  - **Right Subclavian**
    - Extends from the innominate to the first rib.
    - Branches are
      - Vertebral, thyrocervical.
      - Internal mammary.
      - Costocervical.
  - **Left Subclavian**
    - Extends from arch of aorta to first rib.
    - Same branches as right subclavian.
  - **Axillary arteries**
    - In axillary regions.
    - Branches to shoulders, chest, and arms.
  - **Brachial arteries**
    - Extend from axillary arteries to below bend of elbows where they divide into ulnar and radial arteries.
  - **Ulnar arteries**
    - Extend along ulnar border of forearms to palms of hands.
  - **Radial arteries**
    - Extend along radial side of forearms to palms of hands.
  - (Ulnar and radial arteries) Form the superficial and deep **Volar arches.**
- **Arteries of the Lower Extremities**
  - **External Iliacs** form main arteries of lower limbs. Different portions named according to regions through which they pass.
  - **Femoral Arteries**
    - Extend along inguinal ligaments to openings in adductor magnus muscles. Send branches to abdominal walls, external genitals, muscles, and fasciæ of the thighs.
  - **Popliteal Arteries**
    - Back of knees, send branches to knee joints, posterior femoral muscles, gastrocnemius, soleus, skin of back of legs. Below knee joints divides into posterior tibials and anterior tibials.
  - **Posterior Tibials**
    - Back of legs, from bifurcation of popliteal to ankle. Send branches to back of legs and to tibias and fibulas. Gives off peroneal arteries about 1 in. below bifurcation of popliteals. *Peroneals* distribute blood to fibulas and calcaneus bones.

- **Arteries of the Lower Extremities**
  - **Anterior Tibials** — Front of legs from bifurcation of popliteal to ankle — then becomes the *dorsalis pedis* arteries.
  - **Dorsalis Pedis Arteries** — Dorsum of each foot, anastomose with branches from posterior tibials, and supply blood to feet.
- **Veins**
  - Begin small, grow larger.
  - **Differ from arteries**
    - Larger size.
    - Greater number.
    - Thinner walls.
    - Valves.
    - More frequent anastomoses.
  - **Sets**
    - Superficial or cutaneous beneath the skin.
    - Deep
      - Usually accompany the arteries.
      - Exceptions are
        - Veins in skull and vertebral canal.
        - Hepatic veins.
        - Large coronary veins.
    - Venous sinuses — canals formed by separation of layers of dura mater.
  - **Venæ Comitantes** — Deep veins accompanying smaller arteries, such as brachial, radial, ulnar, peroneal tibial, are in pairs. A single deep vein accompanying a larger artery, such as femoral, popliteal, axillary, and subclavian artery, is called a *vena comes.*
  - **Three Groups**
    - Heart — receives blood from coronary veins.
    - Superior Vena Cava — Veins of head, neck, thorax, and upper extremities, empty into this vein.
    - Inferior Vena Cava — Veins of abdomen, pelvis, and lower extremities, empty into this vein.
- **Veins of Neck.**
  - **External Jugulars** — Formed in parotid glands, terminate in the subclavians. Receive blood from deep parts of the face and the exterior of the cranium.
  - **Internal Jugulars** — Continuous with the lateral sinuses, unite with subclavians to form the innominates. Receive blood from the veins and sinuses of the cranial cavity, superficial parts of face and neck.
- **Veins of the Upper Extremities**
  - **Superficial Veins**
    - Are larger, take a greater share in returning blood.
    - **Cephalics** — Begin in dorsal venous network, join accessory cephalics of arms below elbows, empty into axillaries.
    - **Basilics** — Begin in dorsal venous network, are joined by median basilics below elbows, are continued as axillaries.

- **Veins of the Upper Extremities**
  - **Deep Veins**
    - Accompany arteries, are called by same names, *i.e.*, metacarpals, radials, ulnars, brachials, axillaries, and subclavians.
    - **Axillaries** — Are continuations of the basilics, end at outer border of first ribs, receive brachials, cephalics, and deep veins.
    - **Subclavians** — Are continuations of the axillaries, unite with internal jugulars to form innominates.
- **Veins of the Thorax**
  - **Innominates**
    - Formed by union of internal jugular and subclavians.
    - One on each side of body.
  - **Superior Vena Cava**
    - Formed by union of right and left innominate veins. 7.5 cm. long.
    - Opens into right atrium.
  - **Supplementary Channel**
    - 1. Azygos vein
    - 2. Hemiazygos vein
    - 3. Accessory hemiazygos vein
    - Connect with superior vena cava above, and inferior vena cava below.
  - **Bronchial Veins**
    - Formed at the root of each lung.
    - Return blood from larger bronchi and structures at root of lungs.
    - Right bronchial vein empties into azygos vein.
    - Left bronchial vein empties into highest left intercostal or the accessory hemiazygos.
- **Veins of the Lower Extremities**
  - **Superficial Veins**
    - Are between the layers of superficial fasciæ.
    - Provided with valves.
    - **Great Saphenous Veins** — Begin in medial marginal veins, extend upward and end in femoral veins. Receive branches from soles of feet. Anastomose with small saphenous veins, receive cutaneous veins and accessory saphenous veins.
    - **Small Saphenous**
      - Continuation of lateral marginal veins, end in deep popliteal veins.
      - Receive branches on dorsum of each foot and back of each leg.
  - **Deep Veins**
    - Accompany the arteries and are called by same names. Provided with many valves.
    - **Popliteals** — Formed by union of anterior tibial and posterior tibials.
    - **Femorals**
      - Continuation of the popliteals and extend from opening in adductor magnus muscles to the inguinal ligaments.
      - (1) Receive blood from the superficial veins.
      - (2) Receive blood from deep veins of feet, legs, and thighs.

Veins of the Abdomen and Pelvis

- **External Iliacs**
  - Continuation of femoral veins. Extend from inguinal ligaments to the joints between sacral and iliac bones.
- **Hypogastrics**
  - Formed by union of veins corresponding to branches of hypogastric arteries.
- **Common Iliacs**
  - Formed by union of external iliacs and hypogastrics. Extend from base of sacrum to the fifth lumbar vertebra.
- **Inferior Vena Cava**
  - Formed by union of the common iliacs.
  - Extends from fifth lumbar vertebra to the right atrium of the heart.
  - Receives many tributaries corresponding to arteries given off from the aorta.

Portal System

- Blood is collected from spleen by veins that unite to form lienal vein.
- **Lienal vein receives**
  - *Gastric veins* return blood from stomach.
  - *Pancreatic veins* return blood from pancreas.
  - *Inferior mesenteric vein* returns blood from rectum, sigmoid, descending colon.
- **Superior mesenteric vein**
  - Returns blood from small intestine, ascending and transverse colon.
- **Splenic vein and Superior mesenteric**
  - Unite to form Portal tube.
- **Portal tube**
  - Carries blood to liver, breaks up into capillary-like vessels termed sinusoids, then unites with capillaries from hepatic artery to form hepatic vein.
- **Hepatic veins**
  - Formed by union of sinusoids and capillaries from hepatic artery.
  - Empty into Inferior Vena Cava.

CHAPTER XIV

THE GENERAL CIRCULATION; BLOOD-PRESSURE; FETAL CIRCULATION

The blood is contained in a closed set of tubes which it completely fills. Interposed in this set of tubes is the heart which fills with blood from the veins and then contracts, thereby forcing a part of this blood into the lungs and a part to all the rest of the body.

To trace the general circulation,[1] we will begin with the venous blood which is returned to the right atrium by the superior and inferior venæ cavæ. It enters and fills the right atrium and the right ventricle, which for the time being may be thought of as a single chamber with the tricuspid valve open.[2] Then the atrium contracts and forces the blood over the open valve into the ventricle, which has already been passively filled, and now becomes well distended by the extra supply. After a brief pause (possibly 0.1 second), the ventricle contracts, the blood gets behind the cusps of the tricuspid valve, closes them, and (the blood) is forced over the open semilunar valves into the pulmonary artery. The pulmonary artery divides into two branches and carries the blood to the lungs, where it passes through the innumerable capillaries that surround the alveoli or air sacs of the lungs. These capillaries unite to form veins, and these unite to form larger veins, until finally two pulmonary veins return the blood from each lung to the left atrium. The left atrium now contracts and forces the blood over the open bicuspid valve into the left ventricle, just as described for the right side of the heart. The bicuspid valve is closed in the same way as the tricuspid and after a brief pause the left ventricle contracts, forcing the blood over the open semilunar valve, into the aorta. From the aorta and its branches the blood travels in the capillaries to every part of the body. The capillaries unite to form veins, and finally the blood is returned by means of the venæ cavæ to the right atrium, which completes the circuit. This

[1] William Harvey (1578–1657) was a professor in the London College of Physicians. His principal contributions were his researches into and demonstration of the circulation of the blood in 1628.

[2] It is a mistake to think that all the blood accumulates in the atrium before any is forwarded to the ventricle.

description of the general circulation is accurate, but the student must understand that both sides of the heart contract almost simultaneously, *i.e.*, the blood fills the atria and ventricles on both sides of the heart at the same time, both atria contract practically together,[3] forcing the blood over the open valves into the ventricles, moreover the ventricles pump out equal quantities of blood, but the blood from the left ventricle is sent on a longer

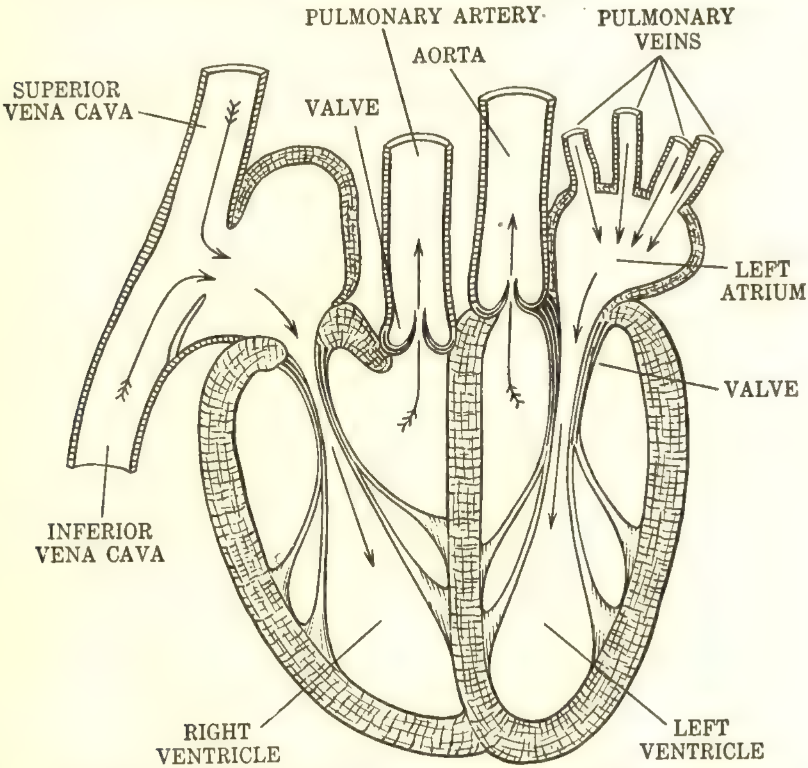


Fig. 176. — A Diagram to Show the Four Chambers of the Heart and the Valves Which Guard Their Openings. From *The Engines of the Human Body* by Arthur Keith. Courtesy of J. B. Lippincott Co.

journey than the blood from the right. After a brief pause both ventricles contract, and the blood is forced into the pulmonary artery, and into the aorta.

The pulmonary circulation. — The lesser circulation, from the right ventricle to the left atrium, is called the pulmonary circulation. The purpose of the pulmonary circulation is to carry the

[3] Careful measurements have shown that the contraction of the left atrium lags behind that of the right atrium from 0.01 to 0.03 of a second.

blood which has been through the body, giving up oxygen and collecting carbon dioxide, to the air sacs of the lungs, where the red cells are recharged with oxygen, and the carbon dioxide is reduced to the standard amount.

The systemic circulation. — The more extensive circulation, from the left ventricle to all parts of the body, and the return to the right atrium, is known as the systemic circulation. The purpose of the systemic circulation is to carry oxygen and nutritive material to all parts of the body, and gather up waste products. After leaving the left ventricle, portions of the blood pursue different courses, some enter the coronary arteries, some go to the

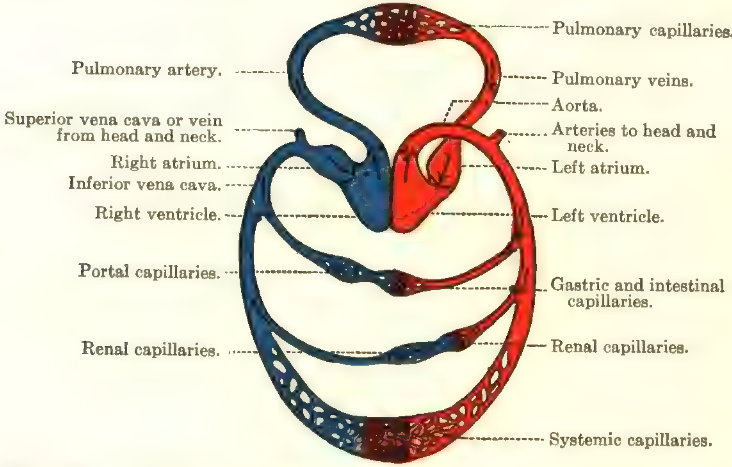


FIG. 177. — DIAGRAM OF THE CIRCULATION. Right and left side are reversed as though the observer were looking at another subject. The pulmonary circulation is from the right ventricle to the left atrium. The systemic circulation is from the left ventricle to the right atrium. (Halliburton.)

head, some to the upper and lower extremities, and some to the different internal organs. Some portions go on shorter journeys and arrive back at the heart sooner than other portions that travel farther away from the center. In man it is thought to require about 23 seconds [4] to complete a circuit of medium length from the left ventricle to the right atrium (systemic circulation). The blood which enters the right atrium has to go through the lungs (pulmonary circulation) before it gets back to the left atrium. This double circulation, pulmonary and systemic, is constantly going on, as each half of the heart is in a literal sense a force pump.

[4] This shows how rapidly substances introduced into the blood-stream can make their way over the body.

The heart as a pump. — The muscles of the atria and ventricles are so arranged that when they contract they lessen the capacity of the chambers which they enclose. When this happens the blood from the contracting chamber is expelled in the direction of the arrows (see Fig. 176), since the valves prevent its passage in the opposite direction.

The first visible sign of contraction is noted when the superior vena cava empties into the right atrium. The sinu-atrial (S-A) node, which lies near the base of the superior vena cava is the causal factor. It is therefore sometimes called the *pacemaker* of the heart. From this spot the wave of contraction passes over the muscles of both atria. These contract simultaneously, driving the blood into the ventricles. The wave of contraction now spreads over the ventricles, causing them to contract simultaneously, driving the blood into the arteries.

The wave of contraction. — If a stimulus be applied to one end of a muscle, a wave of contraction sweeps on over the entire tissue. It is therefore easy to conceive how a wave of contraction can sweep over the muscular tissue of the atria which is practically continuous. The question is — how is this wave transmitted to the muscular tissue of the ventricles which is *not* continuous with that of the atria? The connecting pathway is furnished by the atrioventricular (A-V) bundle which transmits the nerve impulses and causes the wave of contraction to spread over the ventricles.

Heart-block. — Experimentally the atrioventricular bundle may be damaged, with the result that it loses its power to conduct nerve impulses from the atria to the ventricles. The atria will continue to contract at the rate established by the nerve impulses, but the ventricles adopt a slower rate, usually about 30 or 40 a minute. Since the pulse is caused by ventricular contractions, the pulse drops to 30 or 40 per minute. This condition is known as heart-block, and is caused by arteriosclerosis, chronic myocarditis, syphilis, etc., or by overdoses of digitalis.

Fibrillation. — In fibrillation the rhythmic contraction of the atria is interfered with and groups of muscles contract independently of other groups. In consequence the atria undergo irregular twitching movements. This condition affects the contractions of the ventricles, which become irregular and rapid. The pulse is also irregular and rapid. The cause of fibrillation is not known, but it is thought to be related to the formation of nerve impulses in many areas of the heart tissue. Some of the ventricular contractions are so feeble as not to be transmitted to the arteries,

and although they may be heard at the heart, they are not felt at the pulse. There may be a pulse rate of 100, and yet, on listening, it may be discovered that the heart rate is 120. The difference is called the pulse deficit, which in this case is 20. This condition is associated with mitral stenosis[5] and other diseases of the heart valves. Digitalis reduces fibrillation, because its general effect upon the heart is to induce slow, strong, regular, rhythmic contractions, which produce a slow, strong, regular pulse and reduce the pulse deficit.

The heart beat. — By a heart beat is meant a coördinated contraction of the cardiac muscle resulting in the expulsion of blood from both ventricles. It consists of (1) a period of contraction called the *systole*, (2) a period of dilatation called the *diastole*, and (3) a period of rest. These three phases constitute a *cardiac cycle*

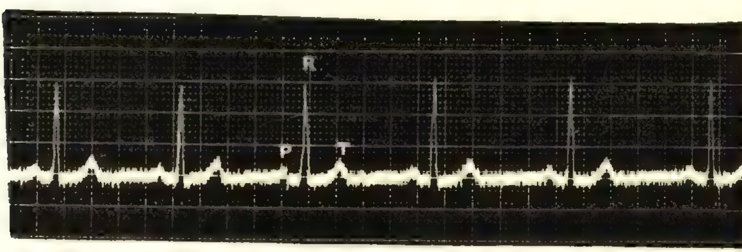


FIG. 178. — ELECTROCARDIOGRAM, showing contraction of different parts of the heart. Waves upward indicate that the base of the heart is negative to the apex. Wave P occurs during atrial systole; waves R, T, occur during ventricular systole.

and correspond to the heart beat. The heart of a man at rest may beat seventy-two times a minute. Some individuals have a lower and others a higher average. If we assume that the heart beats 72 times a minute, the time required for a cardiac cycle is about 0.8 of a second, and half of this, or 0.4 of a second, represents the quiescent phase. When the heart beats more rapidly it is the rest period that is shortened.

Heart sounds and murmurs. — If the ear be applied over the heart, certain sounds are heard, which recur with great regularity. Two chief sounds can be heard during each cardiac cycle. The first sound is a comparatively long, booming sound; the second, a short, sharp, sudden one. The sounds resemble the syllables *lubb dup.* The first sound is thought to be due to the contracting muscle and to vibrations caused by the closure of the atrioventric-

[5] Mitral stenosis is a disease of the mitral valve, in which the atrioventricular opening becomes constricted.

ular valves, the second is attributed to vibrations set up by the sudden closure of the semilunar valves.[6] In certain diseases of the heart these sounds become changed and obscure, and are called murmurs. These are often due to failure of the valves to close properly, thus allowing regurgitation of the blood.

Cause of the heart beat. — The cause of the heart beat is still an unsettled question. Two points of view persist, one, the *neurogenic theory* makes the contained nerve cells responsible for the rhythmic contractions, and the other, the *myogenic theory*, makes the automaticity of the heart muscle responsible. General belief favors the theory that the function of the nerve tissue is regulatory, that the contractions are due to the inherent power of automaticity, and that the stimulus which excites the contractions is a chemical one dependent upon the presence of definite proportions of inorganic salts in the blood. Three are especially important, namely, — calcium, sodium, and potassium. Under normal conditions these salts are always present, and it follows that the heart is subjected to a continual stimulus. It is natural to question why the heart is not in a state of continuous contraction. In other words, how is relaxation possible? In answer it may be stated that there is a well-marked antagonism between the effects of calcium, and the effects of sodium and potassium. Calcium promotes a state of contraction, sodium and potassium promote a state of relaxation. It is possible therefore that the contraction and relaxation characteristic of heart muscle are brought about by interactions of these salts and the muscles of the heart.

Automaticity. — The most remarkable power of cardiac muscle is its automaticity. By this we mean that the stimuli which excite it to activity arise within the tissue itself. Visceral muscle shows an automatic tendency, but this power is most highly developed in the heart. This may be demonstrated by removing the heart of a frog from the body of the animal. The heart will continue to beat for hours provided it is kept moist with Ringer's solution. The degree of automatic power possessed by different regions of the heart varies. Some parts beat faster than others. The most rapidly contracting part is the sinu-atrial node of the right atrium. It is from this particular spot that the wave of contraction radiates through the atrial muscle to the A-V node. From here, it is transmitted over the atrio-ventricular bundle to the ventricles.

[6] Observers have described three sounds, the third a soft low sound at the beginning of the ventricular diastole. Other sounds have also been described.

Nervous control of the heart. — Although the heart contracts automatically and rhythmically, it is under normal conditions controlled by two sets of nerves. These consist of inhibitory nerves coming to the heart from the vagus nerves and accelerator nerves from the thoracolumbar system. The inhibitory nerves have their cell bodies situated in the medulla where they form a cardioinhibitory center. It is assumed that the cardio-accelerator center is also located in the medulla, but the location of this center has not been made out satisfactorily. The way in which these nerves regulate the heart's action is not known, but it is generally believed that both the inhibitory and accelerator nerves are in a state of constant, though slight, activity. This means that the heart beat is controlled by two antagonistic influences, one tending to slow the heart action, and the other to quicken it. If the inhibitory center is stimulated to greater activity, the heart is slowed still further. If the activity of this center is depressed, the heart rate is increased, because the inhibitory action is removed. Stimulation of the accelerator nerves results in a quickened heart beat, and section of these nerves slows the heart.

Factors affecting the frequency and strength of the heart's action. — The frequency and strength of the heart's action are affected by (1) the temperature of the blood; (2) such characteristics of heart muscle as tone, irritability, contractility, conductivity, and (3) physical factors such as size, sex, age, posture, and muscular exercise; (4) changes in the condition of the blood-vessels, and (5) certain internal secretions.

By experimenting on animals it has been possible to demonstrate that abnormally high or low temperatures of the blood affect the frequency of the heart beat. If the heart is perfused with hot liquid the rate is increased in proportion to the temperature until the maximum point, about 44° C.[7] (111 F.) is reached. If the temperature is raised above this the heart soon ceases to beat. In fever the increased rate of the heart action is thought to be partly due to the effect of the higher temperature of the blood on the heart muscle. On the other hand, if cold liquid is perfused through an animal heart, the rate is decreased, and it ceases to beat at about 17° C. (62° F.).

Conditions that affect the *irritability, contractility,* and *conductivity* of the heart muscle, or reduce its normal *tone,* are likely to

[7] To change Fahrenheit to Centigrade, subtract 32° and multiply by $\frac{5}{9}$.

To change Centigrade to Fahrenheit, multiply by $\frac{9}{5}$ and add 32°.

change the frequency of the heart beat, either accelerating or slowing the action. If the tone is below par, the strength of the contractions is diminished. The contraction of any kind of muscular tissue is dependent upon the power of conductivity, but cardiac muscle is specially dependent on this power, because the nerve fibers are *not* widely distributed through its substance.

In almost all cases of warm-blooded animals the frequency of the heart beat is in inverse proportion to the *size* of the body. An elephant's heart beats about 25 times per minute, a mouse's heart about 700 times per minute. Generally speaking, the smaller the animal the more rapid is the consumption of oxygen in its tissues. The increased need of oxygen is met by the heart beating more rapidly and thus accelerating the flow of blood.

The frequency of the heart beat is somewhat more rapid in women than in men. Before birth the heart rate of a female fetus is generally 140 to 145 per minute, and that of the male 130 to 135. On this difference attempts to foretell the sex of the fetus are based.

Age has a marked influence. At birth the rate is about 140 per minute; at three years about 100; in youth about 90; in adult life about 75; in old age about 70; and in extreme old age 75 to 80.

The *posture* of the body influences the rate of the heart beat. The rate is higher when an individual is erect than when he is recumbent. Typical figures are: standing 80; sitting 70; and recumbent 66.

If an individual remains in a recumbent position and keeps quiet the work of the heart may be decreased considerably. This is the reason why certain types of heart cases are kept in a recumbent position.

It is a well-known fact that muscular *exercise* increases the frequency of the heart beat. This insures an increased flow of blood and hence increased quantities of food and oxygen as well as more rapid removal of wastes. It is due to (1) the activity of the cardio-inhibitory center in the medulla being depressed by the motor impulses from the more anterior portions of the brain to the muscles, probably by means of collateral fibers to the cardiac center; (2) a stimulation of the cardio-accelerator center; (3) an increased secretion of adrenalin and other hormones which accelerate heart action; (4) increased temperature of the blood; (5) the pressure of the contracting muscles on the veins sending more blood to the heart, so that the right side is filled more rapidly. This increase of venous pressure reflexly accelerates the heart beat.

In order to function properly the heart requires a certain amount of resistance, and normally this is offered by the blood-vessels. The heart will beat more slowly and strongly in response to in-

creased resistance, provided the resistance is not greater than the heart can overcome. In the latter case the heart is likely to dilate and its action becomes frequent and weak. The most common causes of abnormally high resistance are lack of elasticity and hardening of the walls of the arteries (known as arteriosclerosis), and such interference with the venous circulation as occurs in some forms of heart and kidney diseases. When the resistance is below normal, the heart beats become frequent and weak, a condition associated with surgical shock. Lessened resistance is due either to a relaxed condition of the blood-vessels or the loss of much blood, or of much fluid from the blood.

It is probable that certain internal secretions affect the frequency and strength of the heart beat. Thyroid extracts when fed produce a faster and stronger pulse. *Thyroxin*, the active principle of the thyroid secretion, is probably present in the blood. The partial removal of excessively active thyroid glands results in a slower heart rate. *Epinephrin* from the adrenal glands, and *pituitrin* from the pituitary glands affect the frequency and strength of the heart beat. It has been suggested that hormones from the liver and smooth muscles also accelerate the heart.

Distribution of blood to different parts of the body. — In health the quantity of blood contained in the body is always about the same, but the distribution varies, and is determined by the needs of the different parts. When the digestive organs are active, they need an extra supply of blood, which may be furnished in one of two ways, possibly both. The blood-supply to less active organs may be decreased, or the heart rate may be increased with consequent increase in the output of blood. Other causes may result in an increased supply of blood to an organ. If the skin is exposed to high temperatures the arterioles which bring blood to it are dilated, and the blood-flow near the surface is increased. This aids in the radiation of heat and control of body temperature. On the other hand, slight chilling causes contraction of the skin arterioles, and resulting paleness. The blood-supply to the brain is subject to adjustment in accordance with mental activity and emotional states. During normal sleep the blood-supply to the brain is reduced and this is accompanied by an increased supply to the muscles and skin regions. This has been demonstrated by the use of the plethysmograph,[8] an instrument designed to record changes in volume.

[8] Plethysmographs are of different forms, depending on the organ to be observed, but the principle is the same. The organ is enclosed in a case with rigid walls which has an opening connected with a recorder by rigid tubing. The space

Normally the blood-vessels maintain a state of tone that is half way between contraction and dilatation. It is thought that adjustments in the blood-supply to various parts are brought about by increasing or decreasing the tone of the local blood-vessels. Two factors are important, (1) vasomotor nerves and (2) chemical stimuli.

(1) The vasomotor nerves consist of two antagonistic sets of fibers. The vasoconstrictors cause the muscular coats of the blood-vessels to contract and lessen the size of the vessels. The vasodilator fibers increase the size of the blood-vessels, probably by allowing the muscular coats to relax.

(2) Chemical substances, such as the lactic acid and carbon dioxide, produced during muscular activity, may lessen the tone of the blood-vessels in the part affected, resulting in *local* dilatation and an increased supply of blood to the part needing it. At the same time, the acids carried in the blood to the vasoconstrictor center stimulate it and thereby increase the tone of blood-vessels in other parts of the body. On the other hand, hormones, such as epinephrin and pituitrin, cause contraction of the blood-vessels.

Epinephrin and digitalis are used medicinally to cause vasoconstriction, and amyl nitrite is inhaled to bring about vasodilatation, particularly when a condition like angina pectoris[9] makes quick relief necessary. It was formerly thought that changes in the size of the blood-vessels were limited to the arteries. It is now thought that not only the arteries, but the capillaries and veins are capable of dilatation or constriction under the influence of nerve fibers or chemical stimuli.

In surgical shock there is marked interference with the circulation of the blood. Due to dilatation of the capillary bed and consequent increase in the volume of blood in the capillaries, there is marked decrease in arterial pressure, which may fall below the level essential to the welfare of the tissues. It is thought that the dilatation of the capillaries may be brought about by substances such as histamine formed in injured tissues.

Factors maintaining arterial circulation. — The most important factors maintaining arterial circulation are (1) the pumping action of the heart, (2) the extensibility and elasticity of the arterial walls, (3) the peripheral resistance in the region of the small arteries, and (4) the quantity of blood in the body.

in the interior of the instrument not filled by the organ may be filled with air or a fluid. The connections are also filled with air or a fluid. The recorder registers on a drum the volume changes of the enclosed organ.

[9] Angina pectoris is a disease characterized by attacks of severe constricting pains in the chest, which radiate into the left arm. It is accompanied by a great sense of cardiac oppression and usually occurs in arteriocapillary fibrosis with myocarditis.

The extensibility and elasticity of the arterial walls. — Each time the ventricles contract they force a certain amount of blood into arteries that are already full.[10] The extensibility of the arteries enables them to distend and receive this extra supply of blood. This period of distention corresponds to the contraction period of the heart. Just as soon as the force is removed, the elasticity of the arteries causes them to contract, and exerts such a pressure on the contained blood, that this blood is forced into the capillaries just rapidly enough to allow the arteries time to reach their usual size by the beginning of the next contraction period of the heart. They thus serve not only as conducting tubes but exert a force that assists the heart in driving the blood into the capillaries.

The extensibility and elasticity of the arteries change with the health and age of the individual. Sometimes as the result of disease, and usually as we grow older, the arterial walls grow stiffer and more rigid, and become less well adapted for the unceasing work they are called upon to perform. This condition is known as arteriosclerosis.

Peripheral resistance. — The walls of the arterioles and capillaries are not normally as extensile as the larger arteries, and as they are of smaller caliber and more numerous they offer intense resistance to the flow of blood from the arteries. In consequence the blood enters the capillaries in a steady stream.

Quantity of blood. — It is evident that other things being equal the quantity of blood to be moved is an important factor. Except in cases of severe hemorrhage loss of blood is compensated for by a flow of liquid from the tissues into the blood-vessels.

Factors maintaining venous circulation. — The effect of the pumping action of the heart is not entirely spent in forcing the blood through the arteries and capillaries. A little force still remains to propel the blood back to the heart again, and the presence of valves keeps it flowing in the right direction, *i.e.*, toward the heart. The return flow is also favored by (1) the suction action of the heart caused by the emptying of the atria, (2) the heart and respiratory movements which cause continual changes of pressure against the thin-walled veins in the thorax and abdomen, (3) the contractions of the skeletal and visceral muscles which exercise a massaging action upon the veins, and aided by the valves, propel the blood toward the heart.

The velocity of the blood-flow. — In all the large arteries the blood moves rapidly; in the capillaries very slowly; in the veins

[10] Estimated, from 60 to 90 ml. (2 to 3 oz.).

the velocity is augmented as they increase in size, but never equals that in the aorta. The underlying principle is that in any stream the velocity is greatest where the cross-section of the channel is least, and lowest where the cross-section is greatest. The application of this principle requires that we regard the aorta as the narrowest and the capillaries as the widest part of the vascular system. This is readily admitted if we remember that it is the combined channels of millions of capillaries which we have to compare with the aorta. When a vessel divides, the sum of the cross-sections of the two branches is greater than that of the main trunk. Consequently the velocity will be reduced when an

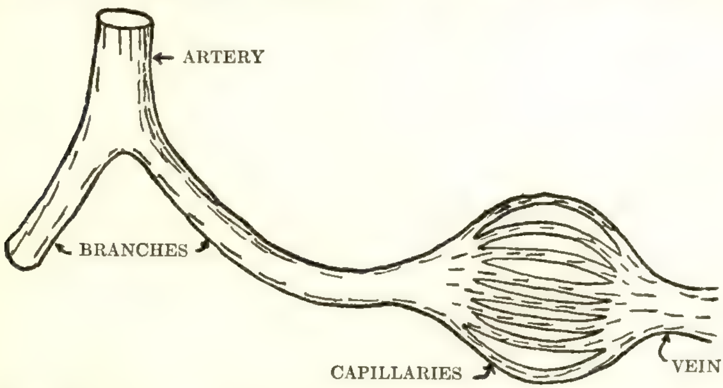


FIG. 179. — DIAGRAM TO ILLUSTRATE VARIATIONS IN VELOCITY OF BLOOD FLOW. If a vessel divides into two branches, these will be individually of less cross-section than the main trunk, but united they will exceed it. Linear velocity will be lower in the branches than in the parent stock. The sum of the cross-sectional areas of the capillaries is greater than that of the artery or vein.

artery divides, and increased when two veins unite to make one. One reason why the velocity in the veins never equals that in the aorta is because the cross-section of the venæ cavæ is greater than the cross-section of the aorta. The actual interchange of materials between the blood and the tissues is rendered in the capillaries (since the wall of the arteries and veins are too thick to permit of diffusion), hence the value of the slow steady flow of blood in this region.

The Pulse. — The alternate dilatation and contraction of an artery constitute the pulse. When the finger is placed on an artery which approaches the surface of the body and is located over a bone, a sense of resistance is felt, which seems to be increased at intervals corresponding to the heart beat. In certain arteries the pulse may be seen with the eye. When the finger is placed on a vein,

very little resistance is felt; and, under ordinary circumstances, no pulse can be perceived by the touch or by the eye.

As each expansion of an artery is produced by a contraction of the heart, the pulse, as felt in any superficial artery, is a convenient guide for ascertaining the character of the heart's action.

All arteries have a pulse, but it is more readily counted wherever an artery approaches the surface of the body. These locations are:

(1) The *radial* artery, on the thumb side of the wrist. The radial artery is usually employed for this purpose, on account of its accessible situation.

(2) The *external maxillary* (*facial*) artery, where it passes over the lower jawbone, which is about on a line with the corners of the mouth.

(3) The *temporal* artery, above and to the outer side of the eye.

(4) The *carotid* artery on the side of the neck.

(5) The *brachial* artery, along the inner side of the biceps.

(6) The *femoral* artery, where it passes over the pelvic bone.

(7) The *popliteal* artery under the knee.

(8) The *dorsalis pedis* over the instep of the foot.

Points to note in feeling a pulse. — In feeling a pulse the following points should be noted:

(1) *The Frequency* or number of beats per minute should be normal for the individual concerned. The intervals between the beats should be of equal length. A pulse may be irregular in frequency and rhythm. When a pulsation is missed at regular or irregular intervals, the pulse is described as *intermittent.*

(2) *The Force or Strength* of the heart beat. Each beat should be of equal strength. Irregularity of strength is due to lack of tone of the cardiac muscle, or of the arteries. Occasionally the heart beat appears to be divided and two pulsations are felt, the second being weaker than the first. This is known as a *dicrotic* pulse. The pulse is studied by the aid of a sphygmograph, which is an instrument that makes graphic tracings of the rise and fall of an artery. It consists of a tension spring to which a button is attached. The button is placed over the artery and the pulsations are communicated to a lever, which records the tracings on paper. Such a tracing shows that a pulse wave consists of two phases: (1) an upstroke, called the anacrotic limb, which is caused by the distension of the vessel and indicates the force of the heart beat; and (2) a down stroke, called the catacrotic limb, which is caused by the recoil of the vessel. Normally the upstroke is smooth, but the downstroke shows several waves. One in the middle is

called the dicrotic wave. In certain diseases this is so exaggerated that it gives the sensation of a double beat and is called a dicrotic pulse.

(3) *The Tension or Resistance* offered by the artery to the finger is an indication of the pressure of the blood within the vessels and the elasticity or inelasticity of the arterial walls. A pulse is described as *soft* when the tension is low and the wall of the artery elastic. A pulse is described as *hard* when the tension is high and the wall of the artery is stiff, thick, and unyielding.

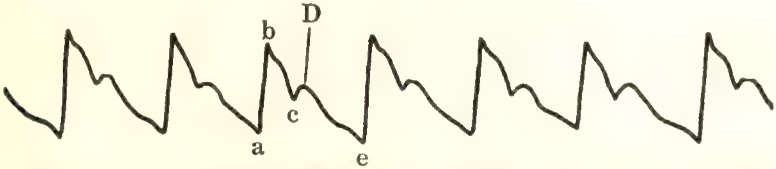


FIG. 180. — SPHYGMOGRAM FROM RADIAL ARTERY. The lever of a sphygmograph can be made to record the pulse wave as a line on a moving surface. Each pulse wave consists of an ascending portion or *anacrotic* limb (*a b*) and a descending or *catacrotic* limb (*b e*). The ascending limb is smooth and steep and records the increasing distension or systolic pressure of the artery. The descending limb is more slanted and shows smaller waves, the most constant of which is the *dicrotic* wave (*D*) which is preceded by the dicrotic notch (*c*). The artery dilates rapidly and steadily but its diameter decreases slowly and irregularly. The dicrotic wave is thought to be due to the closure of the semilunar valve of the aorta.

Average frequency of the pulse. — The average frequency of the pulse in men is 65 to 70, in women, 70 to 80. Idiosyncrasies are frequently met. A person in perfect health may have a much higher or a much lower rate. The relative frequency of the pulse and respirations is about four heart beats to one respiration.

As a rule, the rapidity of the heart's action is in inverse ratio to its force. An infrequent pulse, within physiological limits, is usually a strong one, and a frequent pulse comparatively feeble; the pulse in fever or debilitating affections becoming weaker as it grows more rapid. As the pulse is an indication of the frequency of the heart beat, it follows that the factors which influence the heart beat will also influence the pulse.

Blood-pressure. — We define blood-pressure as the pressure the blood exerts against the walls of the vessels in which it is contained. The term includes arterial, capillary, and venous pressure, but it is commonly applied to pressure existing in the large arteries. A vein is easily flattened under the finger; an artery offers a stronger resistance. This is an indication of a great difference between arterial and venous pressure. This difference is also shown when an artery and a vein are cut; the blood springs from the artery in a

pulsating spurt indicating a high pressure, while the flow from the vein is continuous and even when copious "wells up" rather than "spurts out," indicating a low pressure.

Blood-pressure is highest in the arteries during the period of ventricular contraction. This is systolic pressure. During ventricular diastole blood-pressure tends to fall and reaches a minimum just before the beginning of the next systole. The minimum is called diastolic pressure. Pressure in the arteries is high and fluctuating, slightly higher in the large trunks than in their branches. When the blood reaches the capillaries, the surface is multiplied and the friction increased. This offers an impediment to the flow, and the result is a *decided drop in the pressure.* Pressure in the veins is low and relatively constant. It must be higher in the small veins than in the large ones they unite to form, because the direction of the blood-flow is from the smaller to the larger ones.

Normal degree of blood-pressure. — The average blood-pressure of an adult male as recorded by the sphygmomanometer over the brachial artery is about 110 to 120 mms. systolic and 65–80 mms. diastolic.[11] Some observers report that the systolic pressure is higher in men than in women. Individual variations are not uncommon, but 140 mm. for men, and 130 mm. for women is considered the normal upper limit. A systolic pressure of 150 mm. suggests hypertension. It varies during mental and muscular work and shows a tendency to fall during fatigue. Cold, drugs, etc., which constrict the arterial pulse may raise the blood-pressure. Heat, and the drugs of the vasodilator group like nitroglycerin, may lower it.

Blood-pressure is dependent upon 1, the force of the contraction of the ventricles, 2, the elasticity of the arteries and the tone of the muscular tissue in their walls, 3, the resistance offered to the flow of blood through the vessels. Minor factors are (1) respiration and the accompanying changes in the chest cavity, (2) the amount of blood in the body, and (3) gravity. Gravity tends to increase pressure in arteries below the level of the heart and to decrease pressure in arteries at levels above the heart.

Venous pressure is low, but when standing the pressure in the veins of the legs and feet is high, due to gravity; hence the frequency of varicose veins in the lower limbs. Walking relieves this

[11] The figures given above are the averages usually stated. Various other figures are given in reports of technical studies. See *Blood-Pressure Determination* by William G. Middleton, M.D., *American Journal of Nursing*, Oct., 1930.

pressure because the contraction of the muscles forces the blood upward in the veins, and the valves favor this movement.

Blood-pressure is increased above normal (1) when the elasticity of the arteries is reduced as in arteriosclerosis; (2) by various diseases of the heart, liver, and kidneys which interfere with the venous circulation; (3) by stimulation from the vasoconstrictor center in the medulla; and (4) usually by fever.

FIG. 181. — SPHYGMOMANOMETER. (Courtesy of W. H. Baum Co., Inc.)

Naturally blood-pressure is reduced (1) when the heart beat is weak, (2) when the blood-vessels are relaxed, and (3) when the total quantity of blood in the vessels is reduced.

Method of determining blood-pressure. — It is customary to try the pulse at the wrist to determine whether an individual has high blood-pressure. If the radial artery is hard and incompressible it may indicate either that some change has occurred in the vessel, or that the pressure is high. If, however, the pulse is easy to obliterate with the fingers it is usual to find a low pressure.

Many forms of apparatus have been devised by which a more accurate knowledge of this condition can be obtained. This apparatus is called a sphygmomanometer, and consists of a scaled column of mercury (mercurial manometer) marked in millimeters which is connected by rubber tubing with an elastic air bag contained in a leather cuff. The air bag is in turn connected with a small hand pump. Some instruments are constructed with a spring scale (aneroid manometer) but the principle is the same. The air bag contained in the cuff is wrapped snugly about the arm just above the elbow, over the brachial artery. By placing the finger upon the pulse at the wrist (as we inflate the bag)

we finally reach a point where the pulse disappears, then the bag is very slowly deflated until the pulse can just be felt. The pressure in the bag, therefore, against the artery from the outside, as indicated on the instrument by the number of millimeters that the mercury is raised, is equal to the pressure which the blood exerts against the wall of the artery from the inside. This is known as the systolic pressure, and is the greatest pressure which the contractions of the heart (systole) cause in the brachial artery. Another method of reading blood-pressure is to place a stethoscope over the brachial artery in the bend of the elbow. Blood-pressure is then indicated by sounds heard through the stethoscope. The bag is inflated as before, until all sounds cease. It is then slowly deflated until the pulse can just be heard. The reading on the manometer at this time indicates systolic pressure. The deflation of the bag is then continued, and the reading on the manometer just before the last sound of the disappearing pulse indicates diastolic pressure, which is the lowest pressure which the dilatation of the heart causes in the brachial artery.

Pulse-pressure is the difference between the systolic and diastolic pressure, *viz.*, if the systolic is 115 mm. and the diastolic 75 mm. the pulse-pressure will be 40 mm. The pulse-pressure is an indication of (1) how well the heart is overcoming the resistance offered it, (2) how successfully it is driving the blood to the periphery, and (3) the condition of the arteries, for in arteriosclerosis the pulse-pressure is high. Pulse-pressure varies and is dependent upon (1) the energy of the heart, (2) the elasticity of the blood-vessels, (3) the peripheral resistance, and (4) the quantity of circulating blood.

FETAL CIRCULATION

Certain structures are necessary to the performance of fetal circulation, but are of no use after birth. They are as follows:

(1) **Foramen ovale.** — An opening between the two atria. It furnishes direct communication between them.

(2) **Ductus arteriosus.** — A blood-vessel connecting the pulmonary artery with the aorta.

(3) **Ductus venosus.** — A blood-vessel connecting the umbilical vein and the inferior vena cava.

(4) **The placenta and umbilical cord.** — The fetal placenta is a mass of tissue, rich in blood-vessels, which is in close contact with the lining of the uterus. The umbilical cord unites the placenta with the navel of the child. The cord is made up of two arteries

and one large vein protected by Wharton's jelly. The arteries are branches of the arterial system of the fetus and carry blood from the fetus to the fetal placenta, where it is separated by the thinnest of walls from the maternal blood in the blood-vessels of the uterus. The usual distinctions between arterial and venous blood cannot be recognized, as the blood of the fetus is never up to the arterial standard of the mother. The best blood is that which has been improved by effecting exchanges with the blood in the uterine vessels, and is carried from the placenta to the fetus by the umbilical vein. By means of the placenta the fetus obtains oxygen; the placenta is also the seat of the absorption of food, and the unloading of wastes. Consequently it represents a combination of organs, and serves as the respiratory, digestive, and excretory mechanism for the fetus.

Course of the blood. — The blood is carried from the placenta along the umbilical cord by the umbilical vein. Entering the fetus it is conveyed into the ascending vena cava partly through the liver but chiefly through the ductus venosus, which connects these two vessels. From the ascending vena cava it enters the right atrium, passes through the foramen ovale into the left atrium, thence into the left ventricle, and out through the aorta, which distributes it principally to the head and upper extremities. The blood from the head and upper extremities returns by the descending vena cava to the right atrium, then passes into the right ventricle, and out through the pulmonary artery to the lungs. As the lungs in the fetus are solid, they require very little blood (only for nutrition), the greater part of the blood passes through the ductus arteriosus into the descending aorta, where, mixing with the blood delivered to the aorta by the left ventricle, it descends to supply the viscera of the abdomen and pelvis and the lower extremities. The greater amount of this blood is carried to the placenta by the two umbilical arteries, but a small amount passes back into the ascending vena cava and mixes with the blood from the placenta.

From this description of the fetal circulation, it follows:

1. That the placenta serves the purpose of a respiratory, nutritive, and excretory organ.

2. That the liver receives blood directly from the placenta; hence the large size of the liver at birth.

3. That the blood from the placenta passes almost directly into the arch of the aorta, and is distributed by its branches to the head and upper extremities.

4. That the blood in the descending aorta is chiefly derived

from that which has already circulated in the upper extremities, and, mixed with only a small quantity from the left ventricle, is distributed to the lower extremities.

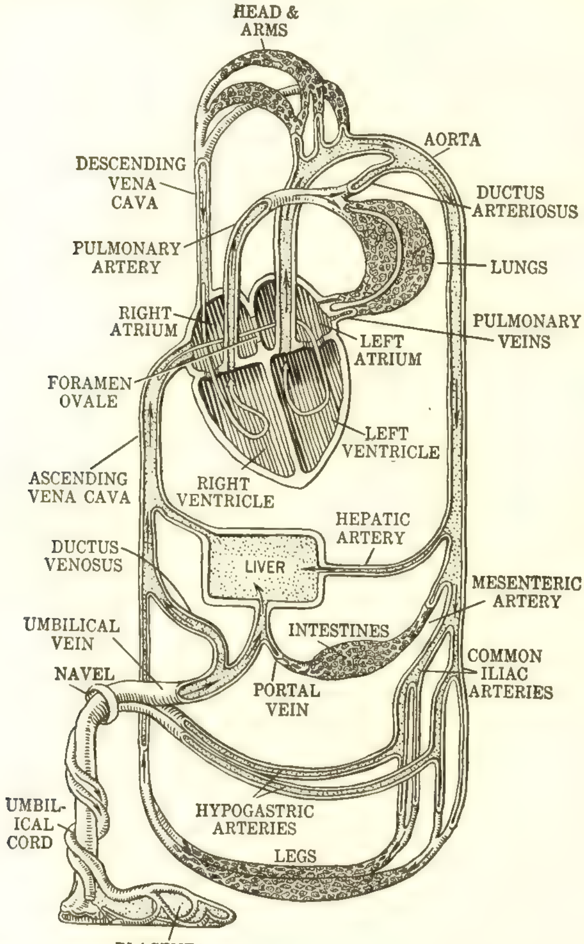


FIG. 182. — Diagram showing course of fetal circulation through hypogastric arteries, ductus venosus, ductus arteriosus, and the foramen ovale. (From *The American Textbook on Obstetrics.*)

Changes in the vascular system at birth. — From the foregoing description it is obvious that at birth very important changes must take place:

1. The blood clots in the umbilical vein, between the usual ligature and the liver, also in the ductus venosus. The blood-clot becomes organized and these two vessels become fibrous cords.

2. As respiration commences, the blood traverses the pulmonary arteries, and then returns to the heart by the pulmonary veins; this raises the blood-pressure in the left atrium, and causes

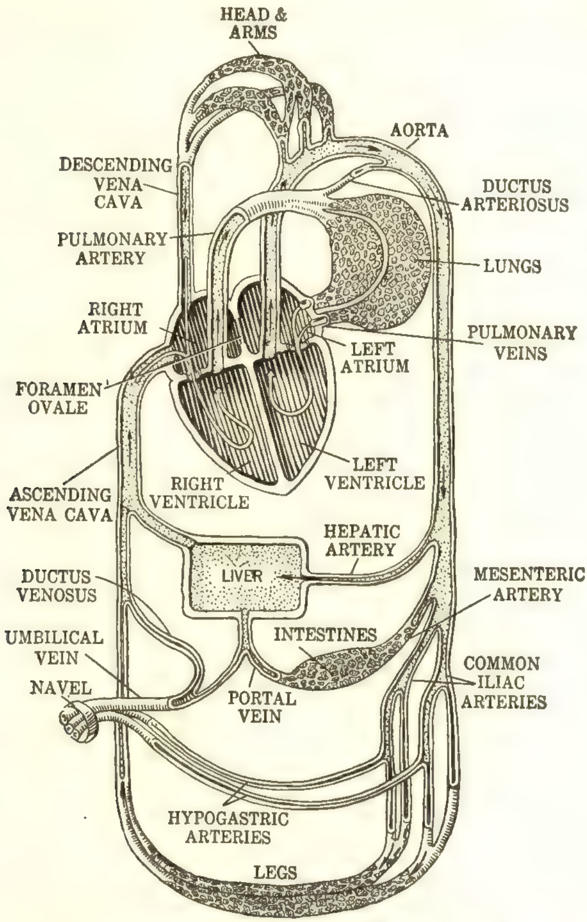


Fig. 183. — Diagram showing circulation of the blood after birth, with hypogastric arteries, ductus venosus, ductus arteriosus, and foramen ovale in process of obliteration and pulmonary circulation greatly increased. (From *The American Textbook on Obstetrics.*)

the valve over the foramen ovale to close. This usually occurs soon after birth.

3. The blood in the ductus arteriosus clots, the clot organizes, and the ductus arteriosus becomes a fibrous cord.

4. The blood in the hypogastric arteries also clots, the clots organize, and these vessels become fibrous cords.

Occasionally some of the embryonic by-passes fail to close, and

so much venous blood enters the arterial system that a *blue baby* is the result. In such instances the child suffers from malnutrition and the chances for survival are slight.

SUMMARY

- **Blood Vascular System**
  - **Pulmonary Circulation**
    - Right ventricle, then pulmonary arteries to lungs. Capillary system. Return by pulmonary veins to left atrium.
    - Purpose — To increase oxygen and decrease carbon dioxide to standard amount.
  - **General or Systematic Circulation**
    - Left ventricle, then by means of aorta and its branches to all parts of the body. Capillary system. Return by veins which empty into superior and inferior venæ cavæ. These empty into right atrium.
    - Thought to require about 23 sec. for circuit of medium length.
    - **Purpose**
      - Carry, and give up to the cells
        - Oxygen.
        - Nutritive materials.
      - Take from the cells
        - Excess carbon dioxide.
        - Other waste products.
- **Heart**
  - **Pumping Action**
    - Muscles contract and lessen capacity of atria and ventricles, thus forcing blood into arteries.
  - **Wave of Contraction**
    - Starts at sinu-atrial node, transmitted through the atrial muscle to the A-V node, which in turn transmits it via the A-V bundle to the ventricles.
    - *Heart-block* — Condition resulting from damage to atrioventricular bundle and consequent failure to transmit impulses from atria to ventricles. Rate of contraction of ventricles slower than that of atria.
    - *Fibrillation* — Rhythmic contractions interfered with. Atria undergo irregular twitching movements. Contractions of ventricles irregular and rapid. Difference between heart rate and pulse called *pulse deficit*.
  - **Heart Beat**
    - Coördinated contraction of cardiac muscle.
    - 1. **Systole** — Contraction
      2. **Diastole** — Dilatation
      3. **Rest** — Quiescent
      - Cardiac cycle, 72 per min.
      - Occupies about 0.8 of a second.
      - Diastole and rest period about 0.44 sec.
    - **Cause**
      - Neurogenic theory makes contained nerves responsible. Myogenic theory makes automaticity responsible.
      - Stimulated by chlorides
        - Sodium.
        - Potassium.
        - Calcium.
      - Innervation is regulatory
        - Inhibition from vagi.
        - Acceleration from autonomic system.

- **Heart**
  - **Heart Sounds**
    - Lubb
      - Vibrations caused by closure of atrioventricular valves and contraction of the ventricles.
    - Dup
      - Vibrations caused by closure of the semilunar valves.
    - Other sounds have been described.

- **Factors affecting the frequency and strength of the heart's action**
  - **Temperature of blood**
    - Elevated temperature increases rate, and low temperature decreases rate of heart beat.
  - **Characteristics of Heart Muscle**
    - **Tone**
    - **Irritability**
    - **Conductivity**
    - **Contractility**
      - Anything affecting these factors likely to affect frequency and force of heart's action. Cardiac muscle specially dependent on property of conductivity.
  - **Physical**
    - **Size** — Frequency of heart beat is in inverse proportion to size of animal. Elephant 25 per minute, mouse 700 per minute.
    - **Sex** — Frequency of heart beat higher in women than in men.
    - **Age**
      - At birth about 140 per minute.
      - At three years about 100 per minute.
      - In youth about 90 per minute.
      - Adult life about 75.
      - Old age 75–80.
    - **Posture**
      1. Erect posture — about 80.
      2. Sitting position — about 70.
      3. Recumbent — about 66.
    - **Muscular Exercise**
      - Increases frequency of heart beat.
        1. Activity of the cardiac inhibitory center in the medulla depressed by motor impulses from brain to muscles.
        2. Stimulation of cardiac accelerator center.
        3. Heart action accelerated by adrenalin and other hormones.
        4. Increased temperature of the blood.
        5. Pressure of contracting muscles sends more blood to the heart.
    - **Resistance**
      - Normally heart requires certain amount of resistance — offered by blood-vessels.
      - Normal amount — heart action slow and strong.
      - Increased amount — heart action frequent and weak.
    - **Condition of blood-vessels**
      - Arteriosclerosis — loss of elasticity of arteries.
      - Relaxation or loss of tone due to loss of blood or of much fluid from the blood.
  - **Internal Secretions**
    - The thyroid — thyroxin.
    - The adrenals — epinephrin.
    - The pituitary — pituitrin.

- **Distribution of blood to different parts of the body**
  - Quantity of blood in body usually about the same but quantity in any given part adjusted to needs.
  - Adjustments dependent on
    1. Vasomotor nerves.
    2. Chemical stimuli.

- **Factors Maintaining Arterial Circulation**
  1. Pumping action of the heart.
  2. The extensibility and elasticity of the arterial walls.
  3. Peripheral resistance.
  4. The quantity of blood in the body.

- **Factors Maintaining Venous Circulation**
  1. Some force due to pumping action of the heart.
  2. Suction action of the heart.
  3. Changes of pressure in thorax and abdomen due to heart and respiratory movements.
  4. Contractions of the skeletal muscles.

- **Velocity of Blood-flow**
  - Arteries — blood moves rapidly in large arteries, more slowly in smaller ones.
  - Capillaries — blood moves very slowly.
  - Veins — blood moves slowly in small veins, more rapidly in larger veins, but never as rapidly as in arteries.

- **Pulse**
  - Alternate dilatation and contraction of artery, corresponding to heart beat.
  - Locations where pulse may be counted
    - Radial artery.
    - External maxillary artery.
    - Temporary artery.
    - Carotid artery.
    - Brachial artery.
    - Femoral artery.
    - Popliteal artery.
    - Dorsalis pedis.
  - Points to note
    - Frequency
    - Force or strength.
    - Tension or resistance
      - Hard.
      - Soft.
  - Pulse Rate
    - Factors which influence heart beat also influence pulse.
    - Average
      - 65–70 in men.
      - 70–80 in women.
    - Ratio of pulse to respiration is about 4 to 1.

- **Blood-Pressure**
  - Pressure blood exerts against walls of vessels.
  - Arterial
    - High and fluctuating.
    - Not uniform
      1. Highest during ventricular contraction = systolic pressure.
      2. Lowest before beginning of next systole = diastolic pressure.
      3. Increases with age.
      4. Decreases if heart or arteries lose their tone.

Blood-Pressure

- **Venous** — Low and constant.
- **Systolic** — greatest pressure which the contractions of heart cause. Average systolic pressure in brachial artery of adult from 110 to 120 mms.
- **Diastolic** — lowest point to which blood-pressure drops between beats. Average diastolic pressure in brachial artery of adult from 65 to 80 mms.
- **Varies**
  - During mental and muscular work and shows a tendency to fall during fatigue.
  - Cold, drugs, etc., which constrict arterial pulse may raise it.
  - Heat, drugs of the vasodilator group may lower it.
- **Dependent upon**
  - Strength of the heart beat.
  - Elasticity of the arteries and tone of muscular tissue in walls.
  - Resistance offered.
  - Minor factors
    - Respiration and resulting changes in chest cavity.
    - Amount of blood in body.
    - Gravity.
- **Increased by**
  - Arteriosclerosis.
  - Heart, liver, and kidney diseases which interfere with venous circulation.
  - Stimulus from vasoconstrictor center in the medulla which constricts arteries and veins.
  - Fever.
- **Reduced**
  - When the heart beat is weak.
  - When the blood-vessels are relaxed.
  - When the total quantity of blood in the vessels is reduced.
- **Determined by use of sphygmomanometer**
  1. Scaled column of mercury connected with air bag.
  2. An elastic air bag contained in a cuff of leather.
  3. Air bag also connected with hand pump.

Pulse-Pressure

- Difference between systolic and diastolic pressure.
- **Indicates**
  - How well the heart is overcoming resistance offered.
  - How successfully it is driving blood to the periphery.
  - Condition of arteries.
- **Dependent upon**
  - Energy of heart.
  - Elasticity of the blood-vessels.
  - Peripheral resistance.
  - Quantity of blood circulating.

Fetal Circulation	1. Direct communication between right and left atrium by means of foramen ovale. 2. Direct communication between pulmonary artery and aorta, ductus arteriosus. 3. Direct communication between umbilical vein and inferior vena cava, ductus venosus. 4. Oxygen and nutritive substances obtained from placenta. 5. Waste eliminated by placenta.
Changes in Vascular System at Birth	1. Umbilical vein and ductus venosus become fibrous cords. 2. Respiration stimulates pulmonary circulation; this raises the blood-pressure in left atrium, and closes foramen ovale soon after birth. 3. Ductus arteriosus becomes a fibrous cord. 4. Hypogastric arteries become fibrous cords.

CHAPTER XV

LYMPH; THE LYMPH VASCULAR SYSTEM

The blood is contained in a set of closed vessels and does not come into immediate contact with the cells, except with such cells as line the walls of the vessels. This makes a medium of exchange between the blood and the cells necessary. Lymph serves this purpose.

Sources of lymph. — The walls of the capillaries are thin and some of the fluid passes out into the spaces between the cells. *Lymph* is derived from the plasma of the blood mainly by filtration. In addition it is necessary to assume an active secretory process on the part of the endothelial cells of the capillaries.

There are differing points of view in regard to classifying the liquids concerned in the exchange of material between the blood and the tissue cells. Anatomists in general claim that the lymph-vessels form a closed system, and suggest that the name lymph be applied to the fluid within the vessels only, and that the fluid outside of the vessels, in the tissue spaces, be called *tissue fluid.* It is suggested that the term lymph be applied to the tissue fluid in general, *i.e.*, to the fluids in the tissues and to the excess drained off in the lymph capillaries. Here, the name lymph will be used in a collective sense to include the fluids found in the tissues, in the lymph-vessels, in the different serous spaces of the body, *e.g.*, the pericardial, pleural, and peritoneal cavities, and in the spaces of the cerebrum, spinal cord, eyes, ears, and joints. Lacteals are lymph channels in the small intestine. During digestion, they are filled with *chyle*, a milk-white fluid composed mainly of emulsified fat.

- **Lymph**
  - Intercellular — Tissue fluid lies between all cells.
  - Intravascular
    - Lymph in the lymph-vessels.
    - Chyle.
  - Serum
    - Pericardial fluid.
    - Pleural fluid.
    - Peritoneal fluid.
  - Other fluids
    - Cerebrospinal fluid.
    - Synovial fluids and fluids in bursæ.
    - Endo- and perilymph of the internal ears.
    - Fluids of eyes.

Function of the lymph. — The lymph bathes all portions of the body not reached by the blood. It delivers to the cells the

material they need to maintain functional activity, and picks up and returns to the blood the products of this activity, which products may be simple waste, or matters capable of being made use of by some other tissue. There is thus a continual interchange going on between the blood and the lymph. This interchange is effected by means of *diffusion, osmosis,* and *dialysis.*

The lymph becomes altered by the metabolic changes of the tissues which it bathes, and we have three different fluids, separated by the moist membranes which form the walls of the blood-vessels and lymphatics, the blood inside the capillary walls, the lymph in the tissues outside the walls of the blood-vessels, and the lymph in the lymph channels. Some of the constituents of the blood pass into the lymph in the tissue spaces; some of the constituents of the lymph pass into the blood directly, and some into the lymphatics. The capillary walls and walls of the lymph-vessels are permeable and allow water molecules (solvent), and molecules of substances in solution (solute) to pass through. Diffusion of this kind is dependent on differences in concentration of the fluids.

Composition of lymph. — The composition of lymph is similar to that of blood plasma. It is a colorless or yellowish fluid possessing an alkaline reaction, a salty taste, and a faint odor.

When examined under the microscope, it is seen to consist of cells floating in a clear liquid. Its resemblance to the plasma is indicated in the table below.

In consequence of the varying needs and wastes of different tissues at different times, both the lymph and blood must vary in composition in different parts of the body. But the loss and gain is so fairly balanced that the average composition is pretty constantly maintained. The composition of the fluids in the serous, cerebrospinal, and synovial cavities, and the fluids of the eye and ear vary.

Blood	Lymph
Specific gravity about 1.055	Specific gravity varies between 1.015 and 1.023
Contains red cells	May contain a few red cells
Contains white cells	Contains lymphocytes
Contains blood-platelets	Does not contain blood-platelets
A high content of blood proteins	A lower content of blood proteins
A low content of waste products	A higher content of waste products
A high content of nutrients	A lower content of nutrients
Normally — clots quickly and firmly	Clots slowly and does not form a firm clot

LYMPH VASCULAR SYSTEM

As the process of lymph formation is continual, it follows that edema would result from the accumulation of lymph if some system of drainage were not provided to return the lymph to the blood. This drainage system is called the lymph vascular system. Even with this system fluid may accumulate in the tissue spaces.

Lymph Vascular System
- **Lymph-vessels**
  - Lymph capillaries.
  - Lymphatics.
  - Thoracic duct.
  - Right lymphatic duct.
  - Lacteals.
- **Expanded Lymph-spaces**
  - Pleural cavity.
  - Pericardial cavity.
  - Peritoneal cavity.
  - Meningeal spaces.
  - Lymph-spaces of eye and ear.
  - Synovial bursæ.
- **Lymph-nodes**

Lymph-vessels. — The plan upon which the lymphatic system is constructed is similar to that of the blood vascular system, if we omit the heart and the arteries. In the tissues we find the closed ends of minute microscopic vessels, called *lymph capillaries*, which are comparable to, and often larger than, the blood capillaries. The lymph capillaries are distributed in the same manner as the blood capillaries. Just as the blood capillaries unite to form veins, the lymph capillaries unite to form larger vessels called *lymphatics*. The lymphatics continue to unite and form larger and larger vessels until finally they converge into two main channels, (1) the thoracic duct, and (2) the right lymphatic duct.

The thoracic duct begins in the dilatation called the *cisterna chyli* (chyle cistern), located on the front of the body of the second lumbar vertebra. It ascends upward in front of the bodies of the vertebræ, and ends by opening into the innominate vein at the angle of junction of the left internal jugular and left subclavian veins. It is from 38–45 cm. (15 in.) long in the adult, about the size of a goose quill and has several valves. At its termination a pair of valves prevent the passage of venous blood into the duct. It receives the lymph from the left side of the head, neck, and chest, all of the abdomen and both lower limbs, also the chyle from the lacteals. The dilatation below, the cisterna chyli, receives the lymph from the lower extremities and from the walls and viscera of the pelvis and abdomen.

The right lymphatic duct is a short vessel, usually about 1.25 cm. ($\frac{1}{2}$ in.) in length. It pours its contents into the innominate vein at the junction of the right internal jugular and subclavian veins. Its orifice is guarded by two semilunar valves.

The lymphatics from the right side of the head, neck, the right arm, and the upper part of the trunk enter the right lymphatic duct. The parts drained by each are suggested by Fig. 184.

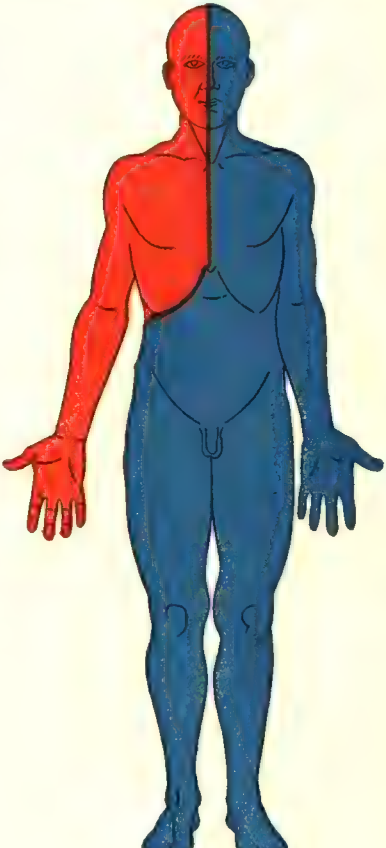


FIG. 184. — THE REGIONS WHOSE LYMPH FLOWS INTO THE RIGHT LYMPHATIC DUCT ARE SUGGESTED BY THE RED AREA; THOSE WHICH ARE TRIBUTARY TO THE THORACIC DUCT BY THE BLUE AREA. (Gerrish.)

Structure of the lymph-vessels. — The lymphatics resemble the veins in their structure as well as in their arrangement. The smallest have but a single coat of endothelial cells, having a peculiar dentated outline. The larger vessels have three coats similar to the veins, except that they are so thin as to be transparent, and are more abundantly supplied with valves. The valves are constructed and arranged in the same fashion as those of the veins but follow one another at such short intervals that, when distended, they give the vessel a beaded or jointed appearance. They are usually absent in the smaller networks. The valves allow the passage of material from the smaller to the larger lymphatics, and from these into the veins, but obstruct the flow in the opposite direction.

FIG. 185. — VALVES OF THE LYMPHATICS

Distribution and classification of lymph-vessels. — Lymph-vessels have been found in nearly every tissue and organ which contains blood-vessels. The cartilage, nails, cuticle, and hair are without them, but it is probable that they permeate all other parts of the body. The lymph, like the blood in the veins, is returned from the limbs and viscera by a superficial and a deep set of vessels. The superficial lymph-vessels are placed immediately beneath the skin, and accompany the superficial veins. In certain situations they join the deep lymphatics by penetrating the deep fasciæ. In the interior of the body they lie in the submucous tissue throughout the whole length of the gastropulmonary and genitourinary tracts, and in the subserous tissue of the thoracic and abdominal walls. The deep lymphatics accompany the deep blood-vessels. They are fewer in number and are larger than the superficial lymphatics.

FIG. 186. — LACTEALS AND LYMPHATICS, DURING DIGESTION.

The lymphatics that have their origin in the villi of the small intestine are called *lacteals*. They are similar to the lymphatics in every way except that during the process of digestion they are filled with chyle which has a white aspect, due to fat absorbed from the food, and suspended in it like oil in milk. A close relationship exists between the lymphatics and the serous cavities of the body, *i.e.*, pleural, pericardial, and peritoneal cavities, the meningeal spaces, lymph-spaces of eye and ear, and the synovial bursæ. These cavities may be considered *expanded lymph spaces.*

Function of the lymphatics. — The function of the lymphatics is to carry from the tissues to the veins all the materials which the

tissues do not need. Functionally they may be considered between the capillaries and the veins, as they gather up the lymph which exudes through the thin capillary walls, and return it to the innominate veins. Here it becomes mixed with the blood, enters the superior vena cava, and then the right atrium of the heart. The function of the lacteals is to help in the absorption of digested food, especially fats.

Lymph-nodes. — The lymph-nodes are small, oval or bean-shaped bodies varying in size from a pinhead to an almond, which are placed in the course of the lymphatics. They generally present a slight depression called the hilus, on one side. The blood-vessels enter and leave through the hilus. The outer covering is a capsule of connective tissue, with some plain muscle fibers. The capsule sends fibrous bands called trabeculæ (little beams) into the substance of the node dividing it into irregular spaces, which communicate freely with each other. The irregular spaces are occupied by a mass of lymphoid tissue, which, however, does not quite fill them as it never touches the capsule or trabeculæ, but leaves a narrow interval between itself and them. It looks as if the pulp had originally filled the framework and then shrunk away slightly on all sides. The spaces thus left form channels for the passage of the lymph, which enters by afferent vessels, at different parts of the surface. After circulating through the node, the lymph is carried out by efferent vessels which emerge from the hilus. The trabeculæ support a free supply of blood-vessels.

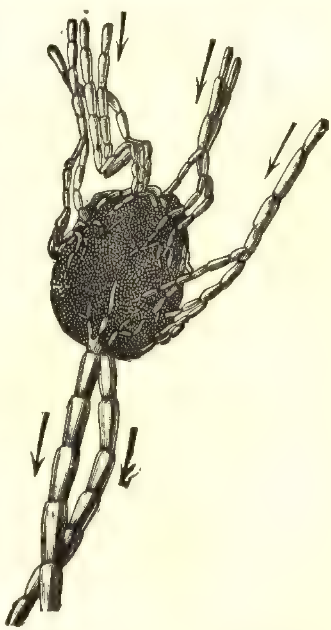


FIG. 187. — A LYMPH-NODE WITH ITS AFFERENT AND EFFERENT VESSELS. (Gerrish.)

Location of nodes. — There is a superficial and a deep set of nodes just as there is a superficial and a deep set of lymphatics and veins. Occasionally a node exists alone, but they are usually in groups or chains at the sides of the great blood-vessels. Lymph-nodes are found (1) on the back of the head, draining the scalp, (2) around the sternomastoid muscle, draining the back of the tongue, the

pharynx, nasal cavities, roof of the mouth and face, and (3) under the rami of the mandible, draining the floor of the mouth.[1]

In the upper extremities there are three groups, — a small one at the bend of the elbow, which drains the hand and forearm, a larger group in the axillary space into which the first group drains,

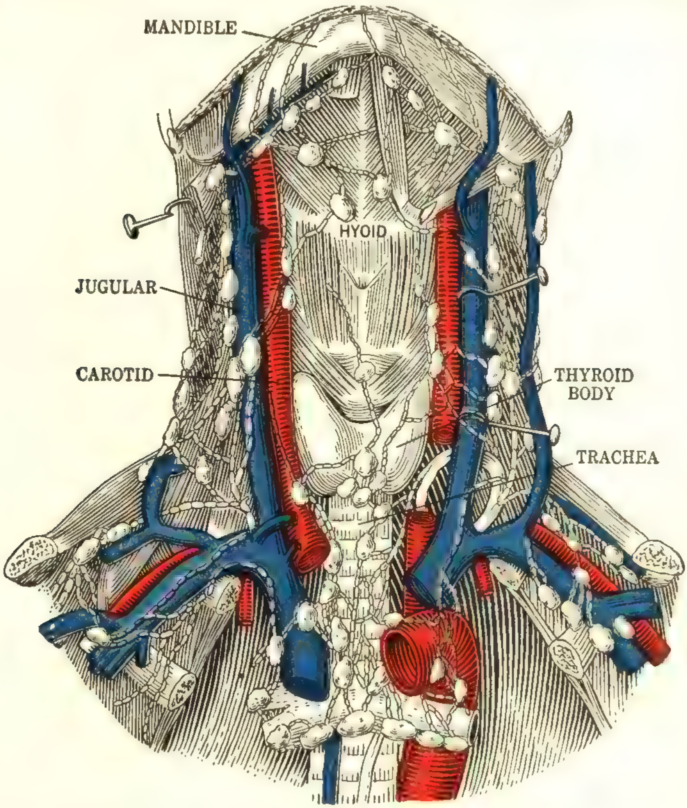


FIG. 188. — THE LYMPH-NODES OF THE NECK AND UPPER PART OF THE THORAX. (Gerrish.)

and a still larger group under the pectoral muscles. The last named drains the mammary gland, skin, and muscles of the chest.

In the lower extremities there is usually a small node at the upper part of the anterior tibial vessels, and in the popliteal space back of the knee there are several, but the greater number are massed in the groin. These nodes drain the lower extremities and the lower part of the abdominal wall. The lymph-nodes of the abdo-

[1] All of these nodes are subject to infection particularly from the tonsils and teeth. Such infection causes an inflammatory condition called adenitis. The nodes around the sternomastoid muscle are very often infected with tubercle bacilli.

men and pelvis are divided into a parietal and a visceral group. The parietal are behind the peritoneum and in close association with the larger blood-vessels. The visceral are associated with the visceral arteries. The lymph-nodes of the thorax are similarly divided into a parietal set situated in the thoracic wall, and a visceral set associated with the heart, pericardium, lungs, pleura, thymus, and esophagus.

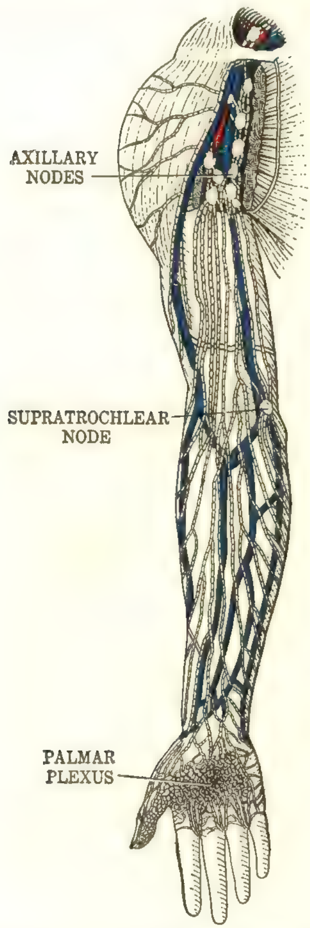


FIG. 189.— THE LYMPH-NODES AND VESSELS OF THE UPPER LIMB. (Gerrish.)

FIG. 190.— THE LYMPH-NODES AND VESSELS OF THE LOWER LIMB. (Gerrish.)

Functions of the lymph-nodes. — The lumph-nodes are credited with two important functions. (1) In its passage through the

node the lymph takes up fresh lymphocytes, which are continually multiplying by cell division in the substance of the node, which is considered the birth-place of these cells.

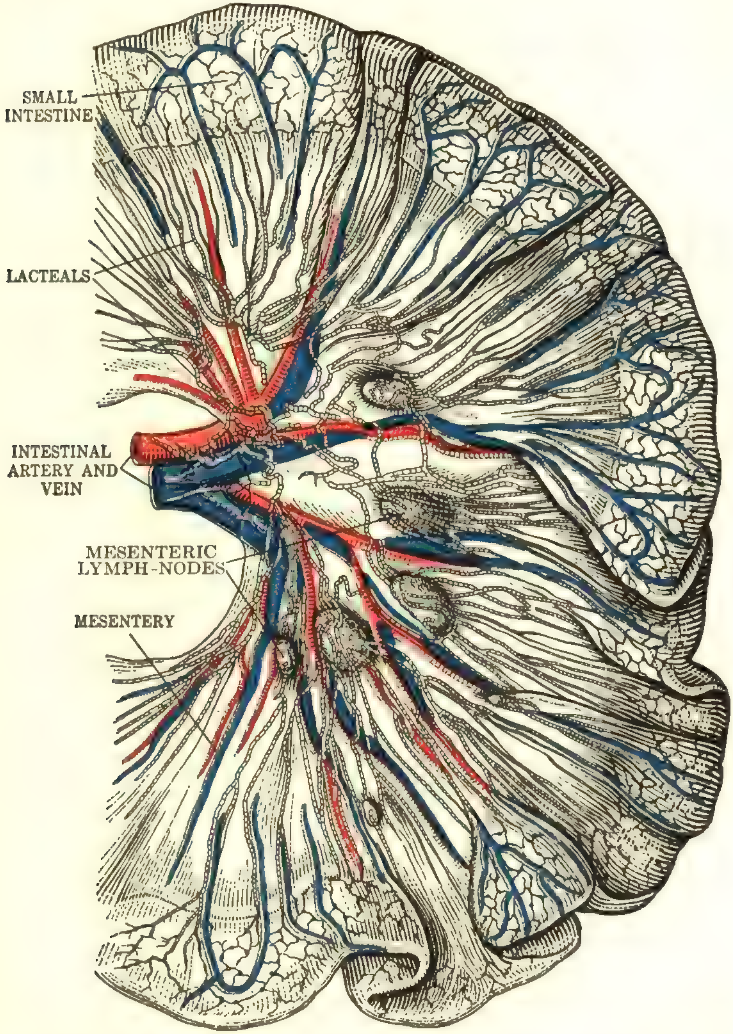


FIG. 191. — THE LACTEALS AND THE MESENTERIC LYMPH-NODES, DEMONSTRATED IN A LOOP OF SMALL INTESTINE BY INJECTION WITH METALLIC MERCURY.

(2) They are placed in the course of the lymph-vessels, and the lymph has to take a tortuous course among the cells of the node. This suggests that they serve as filters and are a defense against the

spread of infection. The lymph draining from an infected area carries the products of suppuration, and perhaps the infecting organisms themselves, to the first nodes in its pathway. Unless the infection is severe, the chances are against the organisms, and the lymph is more or less disinfected before it passes on. Nodes engaged in such a struggle are usually enlarged and tender, and if they are overpowered, they themselves may become the foci of infection, as in scrofula.

Factors controlling the flow of lymph. — The onward progress of the lymph from the tissues to the veins is maintained chiefly by three things.

(1) *Differences in pressure.* — The lymph in the tissues is under greater pressure than the lymph in the lymph capillaries, and the pressure in the larger lymphatics near the ducts is much less than in the smaller vessels. Consequently we may consider that the lymphatics form a system of vessels leading from a region of high pressure, the tissues, to a region of low pressure, the interior of the large veins of the neck.

(2) *Muscular movements and valves.* — Contractions of the skeletal muscles compress the lymph-vessels and force the lymph on toward the larger ducts. The numerous valves prevent a return flow in the wrong direction. The flow of lymph from resting muscles is small in quantity, but during muscular exercise and massage it is increased. The flow of chyle is greatly assisted by the peristaltic and rhythmic contractions of the muscular coats of the intestines.

(3) *Respiratory movements.* — During each inspiration the pressure on the thoracic duct is less than on the lymphatics outside the thorax, and the lymph is accordingly sucked into the duct. During the succeeding expiration the pressure on the thoracic duct is increased, and some of its contents, prevented by the valve from escaping below, are pressed out into the innominate veins.

Edema. — The lymph in the various tissues of the body varies in amount from time to time, but under normal circumstances remains fairly constant. Under abnormal conditions, these limits may be exceeded, and the result is known as edema, or dropsy. Similar excessive accumulations may also occur in the larger lymph spaces, the serous cavities.

Among the possible causes of edema are:

(1) An excessive formation, the lymph gathering in the tissues faster than it can be carried away by a normal flow.

(2) Any obstruction to the flow of lymph from the tissues.

Diffusion. — This term is applied to the spreading or scattering of molecules of gases or liquids. When two gases are brought into contact, the continual movement of the molecules of gas will soon produce a uniform mixture. If a solution of salt is placed in a receptacle and a layer of water poured over it, some of the molecules of salt will pass into the water and produce a solution of uniform composition. Such an interchange would also occur if two solutions of different salts were brought into similar relations with each other.

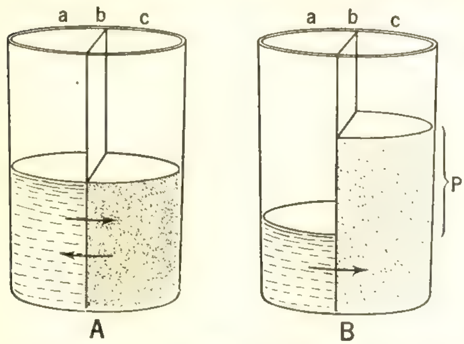


FIG. 192. — DIAGRAM TO ILLUSTRATE OSMOSIS. *a*, chamber containing water; *c*, chamber containing a solution of salt; *b*, membranous partition between the two chambers. In *A*, *b* is permeable to all the substances; in *B*, *b* is semipermeable, impermeable to the salt particles, but permeable to the water particles. *P*, difference of level of the liquids when the chambers are separated by a semipermeable membrane, measures the osmotic pressure.

Osmosis. — The diffusion of water molecules (solvent) through a membrane is called osmosis. If two portions of water are separated by a permeable membrane, the molecules of water will pass from one side to the other and vice versa, so that the level of water on each side of the membrane remains unchanged. We cannot see the movement of the water molecules, but it is assumed to take place on the theory that liquid molecules are in constant motion and the membrane offers no obstacle to their passage through its pores. If a saline solution and water are separated by a permeable membrane, the water molecules will pass through the pores of the membrane to the salt solution, thereby raising the level of the latter. The salt in solution is said to exert a certain *osmotic pressure.* It is due to osmotic pressure that the water flows to the salt side rather than in the reverse direction.

Osmotic pressure varies with the amount of the substance in solution. In physiology the osmotic pressures exerted by different solutions are determined by the way in which they affect the red cells of the blood. In other words, their effect is compared with that of the blood serum. If red cells are subjected to contact with any fluid other than normal serum, they may remain the same, or shrink, or swell. If they remain the same, the solution is said to have the same osmotic pressure as the blood serum, and is called *isotonic* or *isosmotic.* If they shrink, the solution has a higher osmotic pressure than that of blood serum and is called *hypertonic* or *hyperosmotic.* If they swell, the solution has a lower osmotic pressure than that of the blood serum and is called *hypotonic* or *hyposmotic.* Not only water molecules but the molecules of many substances in solution may pass to and fro through membranes, so that two liquids separated by a permeable membrane and originally unlike in composition may by the action of diffusion come to have the same composition.

Dialysis. — The diffusion of molecules of the soluble constituents (solute) through a permeable membrane is called dialysis. If two solutions of unequal concentration are separated by a permeable membrane, a greater number of molecules will pass from the more concentrated solution over to the less concentrated. In time the composition will be the same on both sides of the membrane. This diffusion of soluble constituents from the points of greater to those of less concentration takes place continually, and this may happen quite independently of the direction of the osmotic stream of water.

SUMMARY

- **Lymph**
  - **Sources of Lymph**
    - Physical process of filtration.
    - Active secretory process on part of endothelial cells.
  - **Types**
    - **Intercellular** — Tissue fluid throughout the body.
    - **Intravascular**
      - Lymph in lymph vessels.
      - Chyle.
    - **Serum**
      - Pericardial fluid.
      - Pleural fluid.
      - Peritoneal fluid.
    - **Other fluids**
      - Cerebrospinal fluid.
      - Synovial fluids and fluids in bursæ.
      - Endo- and perilymph of the internal ears.
      - Fluids of eyes.
  - **Functions**
    - Lymph acts as middleman between the blood and the tissues.
    - Carries nourishment *from* blood to tissues.
    - Carries waste from tissues to blood.
    - Dependent upon diffusion.
  - **Description**
    - Colorless or yellowish liquid.
    - Alkaline reaction.
    - Salty taste. No odor.
    - Consists of blood plasma plus lymphocytes.
    - Specific gravity varies between 1.015 and 1.023.
    - Contains a low content of blood-proteins.
    - Contains a low content of nutrients.
    - Contains a high content of waste products.
    - Clots slowly, does not form a firm clot.
- **Lymph Vascular System**
  - **Lymph-vessels**
    - Lymph capillaries.
    - Lymphatics.
    - Thoracic duct.
    - Right lymphatic duct.
    - Lacteals.
  - **Expanded lymph spaces.**
  - **Lymph-nodes.**
- **Lymph-vessels**
  - **Lymph Capillaries**
    - Origin in tissues.
    - One coat of endothelium — dentated.
    - Start as microscopic lymph capillaries, unite to form lymphatics. Comparable to formation of veins.
    - Distribution comparable to blood capillaries.
  - **Lymphatics** — three coats — numerous valves.
  - **Thoracic Duct**
    - Begins in cisterna chyli, located on front of body of 2nd lumbar vertebra.
    - 38–45 cm. long. Size of goose-quill.
    - Has three coats — numerous valves.
    - Receives lymph from left side of head, neck, and chest, left arm, all of abdomen, and both lower limbs. Receives chyle from lacteals.
    - Pours lymph and chyle into left innominate vein.

- **Lymph-vessels**
  - **Right Lymphatic Duct**
    - About 1.25 cm. long.
    - Receives lymph from right side of head, neck, and chest, also right arm.
    - Pours lymph into right innominate vein.
  - **Classification**
    - **Superficial** — beneath skin, accompany superficial veins.
    - **Deep** — accompany deep blood-vessels.
  - **Lacteals**
    - Lymphatics of the intestines.
    - Many originate in villi of small intestine.
    - Contain
      - During digestion — chyle.
      - During period of fasting — lymph.
    - Absorb fatty substances.
  - **Expanded Lymph-spaces**
    - Pleural cavity.
    - Pericardial cavity.
    - Peritoneal cavity.
    - Meningeal spaces.
    - Lymph-spaces of eye and ear.
    - Synovial bursæ.
  - **Function** — Drain off lymph from all parts of the body and return it to the innominate veins.
- **Lymph-nodes**
  - **Description**
    - Shape
      - Oval.
      - Bean-shaped.
    - Size varies from pinhead to almond.
    - Outer capsule — Connective tissue with some muscle fibers.
    - Interior divided into irregular spaces like sponge.
    - Spaces partially filled with lymphoid tissue. Communicating channels for lymph, which enters by afferent, leaves by efferent vessels.
    - Are well supplied with blood.
  - **Location**
    - Superficial and deep set.
    - Usually arranged in groups or chains at sides of great blood-vessels.
    - **Head**
      1. Back of head draining scalp.
      2. Around sterno-mastoid muscle draining
         - Back of tongue, pharynx, nasal civities, roof of mouth, face.
      3. Under rami of mandible — draining floor of mouth.
    - **Upper Extremities**
      1. Small group at bend of elbow drains
         - Hand.
         - Forearm.
      2. Larger axillary group drains
         - First group.
         - Axillary space.
      3. Larger group under pectoral muscles drains
         - Mammary gland.
         - Skin and muscles of chest.

- **Lymph-nodes**
  - **Location**
    - **Lower Extremities**
      1. Node at upper part anterior tibial vessels
      2. Several in popliteal space
      3. Great number massed in groin.

      Drain lower extremities and lower abdominal wall.
    - **Abdomen and Pelvis**
      1. Parietal group — behind peritoneum, in close association with large blood-vessels.
      2. Visceral group — associated with the visceral arteries.
    - **Thorax**
      1. Parietal group situated in thoracic wall.
      2. Visceral group associated with
         - Heart, pericardium.
         - Lungs, pleura.
         - Thymus and esophagus.
  - **Function**
    1. Multiplication of lymphocytes.
    2. Filters — preventive and protective.
- **Factors controlling flow of lymph**
  - Difference in pressure.
  - Muscular movements and valves.
  - Respiration.
- **Edema**
  - Accumulation of lymph in the tissues.
  - **May be caused by**
    1. Excessive formation.
    2. Obstruction to flow of lymph from tissues.
- **Definitions**
  - **Diffusion** — Scattering of molecules of gases or liquids.
  - **Osmosis** — Passage of solvent through membrane.
  - **Dialysis** — Passage of solute through membrane.
  - **Osmotic Pressure**
    - Force exerted by substances in solution.
    - Varies with amount of substance in solution or degree of concentration.
  - **Isotonic** — Same osmotic pressure as blood serum.
  - **Hypertonic** — Higher osmotic pressure than blood serum.
  - **Hypotonic** — Lower osmotic pressure than blood serum.

CHAPTER XVI

GLANDS: SECRETIONS AND EXCRETIONS; ENDOCRINE OR DUCTLESS GLANDS

All of the advances made in the experimental sciences strengthen the idea that the body is a unified whole; there is coöperation, coördination, or integration of the different systems of the body, of the different organs constituting these systems, and of the different tissues and cells. This integration is secured in two ways: (1) through the connections with the nervous system which are maintained throughout all parts of the body and by means of which any part of the body may modify the behavior of any other part, by stimulating or inhibiting the centers that preside over the second part; (2) by chemical products, which are transferred from place to place by the blood, the effect of which is often on an organ distant from the place of their origin.

GLANDS

A gland is a secreting organ, an organ which abstracts certain materials from the blood and makes of them a new substance. All living cells have the power to withdraw from the blood the material they need for their own metabolic activities and to secrete substances which enter the blood. But certain aggregations of cells secrete specific named substances either into cavities in the body, or on the surface of the body, or into the blood-stream, and are named glands. Secretion is the special function of glandular cells.

Size and structure. — The simplest form of a gland may consist of one cell, or may be a mere depression on the surface of a membrane, or may consist of a vast number of secreting recesses. The liver and pancreas are examples of the latter. No matter what the size or shape may be, all glands have three essential characteristics: (1) epithelial cells which are the active secreting agents, (2) a liberal blood-supply from which the material for the secretion is drawn, (3) a basement membrane which serves to hold the cells in position. The usual arrangement is for the cells to cover the free surface of a basement membrane, a dense network of

capillaries to be spread upon its under surface, and nerve fibers to form a network in contact with the cells. In order to economize space and thus provide a more extensive secreting surface, the membrane is generally increased by dipping down and forming variously shaped recesses. (See Fig. 193.)

The stimuli to bring about secretion may be of nervous or chemical origin. Secretion is a sign of irritability and is the response of a secretory cell to stimulation, just as contraction is the response of a muscle cell. The work of the secretory cells consists of two phases, (1) active secretion, including a considerable flow of water, and (2) a period of recovery, during which special substances are produced in the cells. During the second period,

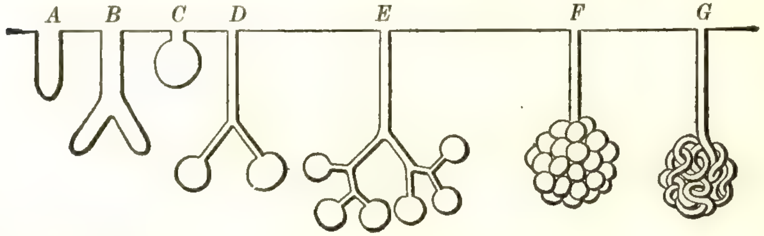


FIG. 193. — DIAGRAM SHOWING KINDS OF GLANDS: *A*, a mere dimple in the surface or a simple tubular gland; *B*, enlargement by division or a branched tubular gland; *C*, enlargement by dilatation or a saccular gland; *D*, a combination of *B* and *C* or a branched saccular gland; *E*, a compound saccular or a racemose gland; *F*, development of method of *E*; *G*, a single tube intricately coiled or a convoluted tubular gland.

the protoplasm of the gland cells becomes filled, and in some cases distended with granules. During active secretion, the granules are lost, the protoplasm clears, and the cells shrink in size.

Classification. — Glands may be classified according to structure and according to function. If classified according to structure, they are of two kinds, (1) simple and (2) compound.

The **simple** glands are generally tubular or saccular cavities, which open upon the surface by a single duct. Sometimes the tube is so long that it coils upon itself, as in the sweat glands of the skin. The cavities from which the duct leads may vary in shape, but the secretory cells surround the cavity, and pour their secretion into it. A group of cells surrounding a tubular or saccular cavity is known as an *acinus* or *alveolus*. A number of such acini when grouped together form a lobule, and a group of lobules constitutes a lobe.

In the **compound** glands the cavities are subdivided into smaller tubular or saccular cavities, opening by small ducts into the main

duct, which pours the secretion upon the surface. If composed of many tubes, either straight or convoluted, they are called compound tubular glands; if composed of groups of small sacs, they are called racemose glands, because they resemble bunches of grapes. The large glands are composed of one or the other or both of these varieties.

Secretion. — A new substance, the product of a gland, elaborated from the blood by cell action, and intended for use in the body is a secretion.

Excretion. — An excretion is a secretion, except that the excretion is generally formed to be thrown out of the body. It therefore follows that all excretions are first secretions, and with the exception of urine all excretions are made use of before they are eliminated. For instance, bile serves several purposes before it is eliminated. On the other hand, urine is a secretion, that is formed only to be eliminated.

Classification. — If classified according to function, glands are of two kinds.

1. Secretory, or those that form secretions.
2. Excretory, or those that form excretions.

The secretory glands are of two types, one type provided with ducts through which the secretion they produce is discharged, and a second type called ductless or endocrine glands, that possess no ducts. The secretion produced by the ductless glands is discharged into the blood, either directly or indirectly by way of the lymphatics. Based on the difference in structure and mode of liberating their secretions, secretory glands are divided into two groups, those producing external secretions, and those producing internal secretions.

External secretions. — This term is used to designate the secretions of glandular tissues which are carried to their destination by a duct. The digestive fluids secreted by the salivary, gastric, and intestinal glands, the pancreas, and the liver, are external secretions. The secretions of the lacrimal, tarsal, ceruminous, sebaceous, and sweat glands are also external secretions. All of these secretions are carried off from the respective glands in which they are formed, by means of ducts.

Functions of external secretions. — The functions of these secretions vary. (1) Those concerned with digestion promote chemical reactions; (2) the lacrimal, tarsal, ceruminous, sebaceous, and sweat-glands moisten, lubricate, and protect the surfaces upon which they are discharged; (3) the perspiration helps in regulating

body heat; (4) the secretion of the mammary glands furnishes nutritive material specially adapted to the needs of the young of the species. Perspiration, bile, and urine are classed as excretions, but they are first secretions and, with the exception of urine, are made use of during discharge.

Enzymes. — The digestive fluids owe their power to promote chemical reactions to enzymes. The exact composition of enzymes is not known. They are complex organic substances[1] which act as catalyzers, *i.e.*, they vary (hasten or retard) the speed of chemical reactions, and are not destroyed or used up in the process. A distinction is made between extracellular enzymes and intracellular enzymes. *Extracellular* enzymes are secreted from the cells and exert their activities outside of them, as do the ptyalin of saliva and the pepsin of the gastric juice, whereas *intracellular* enzymes perform their functions within the cells in which they are made, as in the case of the muscle cells. The term *exoenzymes* is also used for extracellular, and *endoenzymes* for intracellular enzymes.

The following characteristics may be noted: (1) body enzymes act best at the body temperature (optimum); (2) each enzyme requires a medium of definite reaction, either acid, alkaline, or neutral — pepsin acts only in an acid medium, whereas trypsin digests protein in either an alkaline or a neutral solution, but not in the presence of free acid; (3) the action of enzymes is specific, *i.e.*, enzymes that act upon fats do not act upon carbohydrates. In fact each one of the sugars seems to require its own special enzyme. Under proper conditions many chemical reactions may take place in opposite directions, or in other words they are *reversible.* For instance, during digestion, an enzyme called lipase acts upon neutral fats changing them to fatty acids and glycerin. After absorption, fatty acids and glycerin combine to form body fats and it is probable that lipase furthers this synthesis, just as it did the first change. This explains how fat may be stored in the subcutaneous tissues, and when need arises may be changed to fatty acids and glycerin and oxidized.

Active and inactive form. — It has been demonstrated that an enzyme may exist within the cell producing it in an antecedent or *inactive* form and even when secreted may still be inactive. This antecedent or inactive form is designated as a *proferment* or *zymogen.* The zymogen may be stored in the cell in the form of granules which are converted into active enzyme at the moment of secretion, or it may be secreted in inactive form and require the

[1] Catalysts formed in cells.

coöperation of some other substance before it is capable of effecting its normal reaction. In such cases the second substance is said to activate the enzyme. It has been suggested that the inorganic substances causing activation shall be designated as *activators*, and organic substances serving the same purpose shall be named *kinases*. An example of the latter is the enterokinase which activates the trypsinogen of the pancreatic secretion.

Coenzymes. — There are some cases where the action of an enzyme is helped by, or perhaps is dependent upon, the presence of some other substance. A good example of this activity is furnished by the influence of bile-salts upon lipase. These cases of *coactivity* are to be distinguished from activation, by the fact that the combination may be made or unmade. For example, in a mixture of bile-salts and lipase, the bile-salts may be removed by dialysis. In activation, on the contrary, the active enzyme cannot be changed back to the inactive zymogen.

THE ENDOCRINE OR DUCTLESS GLANDS

The endocrine or ductless glands form a group of organs that produce secretions, called internal secretions, which leave the gland by the blood or lymph. Many of the glands that possess ducts and form an external secretion form an internal secretion as well, *i.e.*, the liver and pancreas.

Methods of study. — It is difficult to secure internal secretions in a state of purity, *i.e.*, without the blood or lymph into which they are poured; nevertheless, this has been accomplished, and in one case the extract (adrenalin) has been prepared synthetically. The methods of study have been: (1) observation of the conditions caused by disease of these glands, (2) feeding of glands, of extracts, more recently of active principles or synthetic preparations, (3) subcutaneous or intravenous injection of glandular extracts, and (4) various other experiments.

Function of the endocrines. — The results of many investigations justify the conclusion that the internal secretions contain substances which, taken into the blood and circulated freely through the body, have the power to rouse to action, or to modify the action of, some organ or organs. These substances are called *autacoids*, from Greek words meaning *natural remedy*. Those which activate functions are called *hormones*,[2] and those which depress functions are called *chalones*.[3] However, it must not be

[2] From a Greek word meaning *to excite*.
[3] From a Greek word meaning *to make slack*.

understood that autacoids are found only in the internal secretions. The carbon dioxide formed in the tissues, particularly the muscles, acts as a hormone by stimulating the respiratory center in the medulla; and urea stimulates the kidneys.

Enzymes and hormones are not to be confused. They differ in many ways. A few of these differences are: (1) enyzmes are rendered inactive by boiling, hormones are not; enzymes are not dialyzable, hormones are; one hormone (adrenalin) has been synthesized in the laboratory, enzymes have not been synthesized.

The most important ductless glands are:

1. The Thyroid.
2. The Parathyroids.
3. The Thymus.
4. The Suprarenal Glands or Adrenals.
5. The Pituitary body or Hypophysis.
6. The Pineal body or Epiphysis.
7. The Gonads (ovaries and testes).

Special cells in the pancreas and liver, also portions of the lining membrane of the stomach and intestines function as ductless glands, and furnish internal secretions.

(1) **The thyroid.** — The thyroid is a small, flat gland consisting of a right and left lobe placed on either side of the trachea, below the thyroid cartilage. The lobes are connected by a strand of their own substance, called the isthmus, which stretches across the front of the trachea. The glandular portion is surrounded by fibrous tissue, which extends inward and divides it into masses of irregular size. The essential part of the gland consists of numerous closed vesicles, lined with columnar epithelium. They contain a colloid or jelly-like material and are supported by the fibrous trabeculæ, which extend inward. It contains many lymphatics and an abundant blood-supply derived from the external carotid and the subclavian arteries. The nerves are derived from the cervical portion of the autonomics.

Function. — The thyroid gland furnishes thyroxin (Harrington's formula, $C_{15}H_{11}O_4NI_4$) which is absolutely essential to health. It contains as high as 65 per cent of iodine. The thyroid has the power to store iodine, and selects from the blood the minute quantities of this element absorbed from digested food. In most regions drinking water contains traces of iodine, and is an important source of supply. Sea food contains minute quantities. The general effect of the gland is to control the metabolic rate. It seems to have a part (1) in neutralizing bacterial and other poisons, (2) in keeping the skin and mucous membranes in good condition, and (3) it affects the irritability and response of nerves.

Measurements of basal metabolism[4] show that the internal secretion of the thyroid influences the general rate of oxidation in the body. The simplest measurement is the one in which the amount of oxygen used in respiration is measured for a definite period of time. A perfectly normal person who has fasted for twelve to eighteen hours before the test, and is entirely relaxed during the test and the half hour preceding it, should use a definite amount of oxygen per square meter of body surface. This

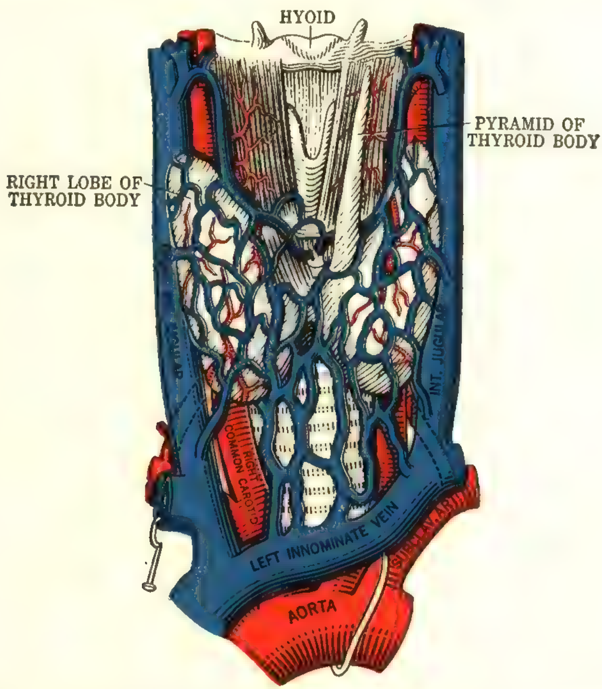


Fig. 194. — The Thyroid Body and the Related Blood-vessels. (Gerrish.)

has been determined for individuals of given height, weight, and age, and is used as a measure of normal basal metabolism. Cases of hypoactivity may show a decrease in basal metabolism of as much as 30 per cent. Cases of hyperactivity show an increase in basal metabolism of from 10 to 40 per cent. Thyroid feeding produces an increase in basal metabolism, a loss of weight, and in some cases an increase in the rate and force of the heart beat, often an irregularity called tachycardia; and may cause nervous excitability and flushing.

[4] See page 467.

The size of the thyroid varies with age, sex, and general nutrition, being relatively larger in youth, in women, and in the well-nourished. Removal or disease of the thyroid resulting in an absence, decrease, or increase of the internal secretion is followed by grave disturbances which are grouped under two headings, *i.e.*, hypothyroidism, or lack of thyroid secretion, and hyperthyroidism, or excess of thyroid secretion.

Hypothyroidism. — In man certain pathological conditions are due to hypothyroidism, *i.e.*, goiter, cretinism, and myxedema.

Goiter is a morbid enlargement of the gland resulting from increased functional activity, due to a decrease in the iodine content of the gland. This in turn is thought to be due to a decrease or lack of iodine in water [5] and food. Good results have been obtained by the administration of small amounts of iodide, or by the use of table salt containing iodine. Goiter is endemic in the "goiter belt" of the United States. This belt stretches along the Appalachian Mountains as far north as Vermont, westward through the Great Lakes region to the State of Washington.

The three periods in which goiter develops are fetal life, adolescence, and pregnancy. In endemic goiter districts, it is recommended that during pregnancy the thyroid be kept saturated with iodine. This will prevent goiter in the mother and child. It is also recommended that during adolescence (11 to 16 years of age) every girl should keep her thyroid saturated and thus prevent goiter at this period.

Cretinism is a species of idiocy due to congenital defects of the thyroid, or atrophy occurring in early life. The growth of the skeleton ceases, though the bones may become thicker than normal and there is complete arrest of mental development. Children so afflicted are called cretins. They are not only dwarfed, but ill-proportioned and ugly, having heavy heads and abdomens and weak muscles.

Myxedema [6] is a condition which results from atrophy or removal of the thyroid in adult life. The most marked symptoms of this condition are slowness both of body and mind, usually associated with tremors and twitchings. The skin becomes rough and dry, due to lack of cutaneous secretions, and assumes a yellow, wax-like appearance. There is an overgrowth of the subcutaneous tissues, which in time is replaced by fat; the hair grows coarse and falls out; the face and hands are swollen and puffy; the body and mind are unwieldy and clumsy. Cretinism and myxedema are both due to lack of the internal secretion of the thyroid, which may be supplied by feeding on the thyroid of other animals. This treatment must be kept up for years. Iodides are beneficial and are sometimes used instead of thyroid extract.

Hyperthyroidism. — Over-activity of the thyroid gland, *i.e.*, increase in the amount of the internal secretion, produces a condition called *Graves' disease* or *exophthalmic goiter.* It is characterized by protruding eyeballs, quickened and sometimes irregular heart action, elevated temperature, nervousness, and insomnia. The appetite may be, often is, excessive, but this is accompanied by loss of weight due to increased metabolism and digestive disturbances. This condition is sometimes remedied by limiting the blood-supply to the gland, either by ligating one of the carotid branches or removing part of the gland.

[5] In some instances iodine has been added to the community water supply with good results. At Rochester, N. Y., sodium iodide is added to the public water supply for a three weeks' period twice a year.

[6] *Myxedema* comes from two Greek words meaning mucous swelling. This name was given because it was thought to be due to an increased amount of mucin.

The parathyroids. — The parathyroids consist of four small glands usually located between the posterior borders of the lateral lobes of the thyroid gland and its capsule. They consist of masses of epithelial cells with numerous capillaries. Each gland is supplied with a special branch from the inferior thyroid artery.

The parathyroids produce a hormone called parathormone, which regulates the blood calcium level.

In hypoparathyroidism, or after the removal of the parathyroids, muscular tetany develops, the blood calcium is at a low level and death may ensue in a few days.

In hyperparathyroidism, there is muscular weakness, pain in muscle and bone and an abnormally high level of calcium in blood and urine.

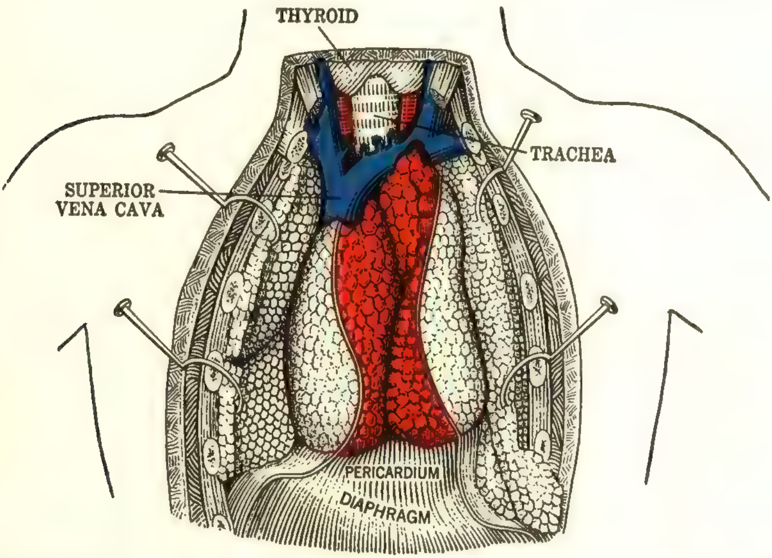


FIG. 195. — THE THYMUS, THE STERNAL AND COSTAL CARTILAGES HAVING BEEN REMOVED. (Gerrish.)

The thymus. — The thymus consists of two lateral lobes, which occasionally unite to form a single mass, or the two lobes may have an intermediate lobe between them. It is situated in the upper chest cavity, along the trachea and overlapping the great blood-vessels as they leave the heart. The structure of the thymus is similar to that of a lymph-node. Each lobule consists of a cortical portion composed of lymphoid cells, supported by an areolar network, and of a medullary portion, in which the reticulum is coarser and the lymphoid cells fewer in number. The medullary portion also contains nest-like bodies, called the corpuscles of

Hassall.[7] The arteries are branches of the internal mammary and the superior and inferior thyroids. The nerves are derived from the vagi and the thoracolumbar autonomics. The thymus is a temporary organ, reaching its greatest size at the time of puberty, when it gradually diminishes. The function of the thymus is obscure. Experimental results are so contradictory that it is a question whether the thymus is a gland of internal secretion. One investigator regards the thymus as the starting point of the lymphoid tissue of the body, and therefore of the lymphocytes. The masses of lymphoid tissue, which form in various parts of the body, are said to be started by lymphocytes, which originally come from the thymus gland. As the secondary masses develop, the thymus atrophies.

Other theories are concerned with the removal of excess of guanidine from the blood, and with the regulation of the calcium content of the blood. It has also been credited with inhibiting the growth of the sex glands. But the whole question is obscure, and it has been denied that the thymus has an internal secretion.

The condition known as *status lymphaticus* is characterized by enlargement and over-activity of the thymus, and enlargement of the lymphoid structures in general.

The suprarenal glands or adrenals. — They are two small, yellowish bodies placed above and in front of the upper ends of the kidneys. The right is somewhat smaller than the left, and is quadrangular, the left being somewhat semilunar in shape. Each gland is surrounded by a thin capsule of fibrous tissue and consists of two parts known as the cortex and the medulla, which differ in origin and in function. The *cortex* consists of masses of epithelial cells arranged in columns. These cells are derived from that portion of the mesoderm which gives rise to the kidneys.

The *medullary portion* consists of large granular cells arranged in a network. When treated with chromic acid,[8] these cells give a characteristic yellow or brown reaction. This reaction has been used to locate similar cells in other tissues. Such cells are frequently found in the sympathetic ganglia. Clumps of such cells lie on either side of the aorta, and are associated with the ganglia of the celiac, renal, suprarenal, aortic, and hypogastric plexuses. The medulla is derived from the same portion (neural crest) of the ectoderm that gives rise to the sympathetic ganglia. It secretes a

[7] Arthur Hill Hassall, English physician, 1817–1894.

[8] Tissues which give the chromophil reaction are grouped as parts of the chromophil system.

substance called epinephrin (Aldrich's formula, $C_9H_{13}NO_3$), which has been isolated in pure form and synthesized in the laboratory.

It is thought that the blood receives a constant though small supply of epinephrin and that this constitutes the internal secretion of the medullary portion. There is great difference of opinion regarding the function of epinephrin under normal conditions. It was formerly thought that it was essential to the maintenance of arterial tone. It is now thought that the secretion of epinephrin constitutes a reserve mechanism that comes into action at times of stress. Under emotional excitement there is an increased secretion, which augments the response of the thoracolumbar nerves, giving a more rapid heart beat, a greater flow of blood to the muscles, central nervous system, and heart, as well as an increased output of glucose from the liver. After many experiments Langley concluded that epinephrin acts only upon the plain muscle which is innervated from the thoracolumbar system, and its effect, whether of stimulation or of inhibition, is similar to that obtained by direct stimulation of the thoracolumbar nerves. It is probable that the functions of the cortex are different from those of the medulla. This view is supported by the fact that the cortex does not contain epinephrin and has a different embryological origin. The results of many experiments indicate that the cortex is essential to life and that it forms some secretion. The nature of this secretion and its normal function are problems requiring further investigation. The arteries supplying the adrenals are derived from the aorta, the inferior phrenic, and the renal. The nerve fibers are derived from the celiac and renal plexuses.

Attention has been called to the probability of a relationship between the adrenals and the gonads, because various phases of sexual life are accompanied by histological changes in the adrenals.

Epinephrin is used in practical surgery. Locally it serves as a styptic. By contracting the arterioles of the skin and mucous membranes, it lessens the loss of blood in minor operations. Subcutaneous or intravenous injections are used in surgical emergencies, to cause a rise of blood-pressure.

The pituitary body or hypophysis. — The pituitary is a mass of reddish gray tissue about 1 cm. in diameter. It is situated at the base of the brain and is lodged in a saddle-like depression — the sella turcica — of the sphenoid bone. It consists of two lobes: the anterior lobe arises as an outgrowth of the ectoderm of the pharynx, and develops into a ductless gland which is extremely vascular; the posterior lobe arises as a downgrowth of cells from the floor of

the third ventricle of the brain. An intermediate part is found in some animals, but not in man; a tuberal part containing colloid material is also described.

Functions of the posterior lobe of the pituitary. A substance called *pituitrin,* or *hypophysin,* is obtained from extract of the posterior lobe. When introduced into the circulation, this extract gives marked reactions. (1) The blood-pressure is raised and the heart rate is slowed. This is called the *pressor effect* and becomes less after a second injection. (2) Contraction of the visceral muscles takes place, especially of the muscles of the intestine. These two effects are said to be due to the hormone *pitressin,* of the pituitrin. (3) The muscles of the uterus contract to a noticeable degree, a result that is known as the oxytocic effect and is attributed to *oxytocin,* or *pitocin,* which is a second hormone of pituitrin. (4) There is increased secretion of urine, which is, however, a transitory effect, and is followed by a lessened secretion. The latter effect is the basis for the medicinal use of pituitary extract in diabetes insipidus, a condition characterized by the excretion of large amounts of urine and abnormal thirst. These symptoms are relieved by injections of pituitrin. (5) An increased flow of milk is brought about in nursing mothers, which is called the galactogogic effect. Recent experiments on animals seem to indicate that the development of the glandular tissue of the breasts after conception is not due to the corpus luteum alone, but is readily produced by extract of hypophysin. These varied reactions suggest the possibility that the extract contains several different active substances. One of these has a stimulating effect on the cells of visceral muscles and of the kidneys.

Pituitrin is used in obstetrics to promote contractions of the uterus, when the cervix is fully dilated and there is no obstruction to the *passage* of the child. It is also used in postpartum and pulmonary hemorrhage.

Functions of the anterior lobe of the pituitary. The injection or feeding of extract of the anterior lobe seems to cause more rapid growth in size and weight of all the organs, except the reproductive organs, and to cause an increase in height. This is due to a growth-promoting hormone. It is claimed that certain abnormalities in the growth of the skeleton are related to an enlargement and presumed hypersecretion of this lobe. If this occurs in the young, the long bones grow to an unusual length, causing increased height — a condition known as *gigantism.* When this occurs in later life, the state known as *acromegaly* develops, in which the bones increase in thickness.

Extracts of the anterior lobe of the pituitary have also a marked effect upon the metabolism of the gonad, due to the *gonad-stimulating* hormone. Injection of this extract, taken from a mature animal, brings about the formation of many follicles in the ovary of the immature. This is the basis of early tests for pregnancy. Removal of the anterior lobe of the pituitary causes a cessation of follicular development in the ovary. Another hormone stimulates the development of the corpora lutea after ovulation.[9]

There is a close physiological relationship between the anterior lobe of the pituitary, the gonads, the thyroid, and the cortex of the adrenals.

The pineal body or epiphysis. — The pineal body is a small reddish gray body about 8 mm. in length, that develops as an outgrowth of the third ventricle of the brain and remains attached to the roof of the ventricle. In early life it is glandular and attains its maximum growth about the seventh year. After this period, and particularly after puberty, it decreases in size, and the glandular tissue is replaced by fibrous tissue. Its function is not known, but it is thought that it furnishes a secretion that inhibits growth and the development of the reproductive organs; however, the evidence in support of this is not conclusive.

Internal secretion of the gonads. — The *ovaries* produce ova and two internal secretions which have been successfully demonstrated in experimental work with animals. There is reason to believe that additional secretions are formed, but they have not yet been successfully worked out. One secretion is formed by the vesicular follicles which contain a hormone called *œstrin* or *theelin.* Theelin is present in the blood of females during the reproductive period from puberty to the menopause, varying in concentration with the phases of the menstrual cycle and reaching its highest concentration just before menstruation. Theelin controls the changing character of the reproductive organs during phases of the menstrual period, and, it is thought, is itself controlled by the gonad-stimulating hormone of the pituitary. It is present in large amounts during pregnancy and appears in the urine and feces. When theelin is injected into an immature female changes in the mucosa of the uterus and vagina similar to those of menstruation take place. A second internal secretion is formed by the cells of the corpus luteum. It is called *progestin.* The luteal secretion sensitizes the mucous membrane of the uterus, so that it responds to the contact of the developing ovum and assists in the process of implantation.

[9] Ascheim and Zondek have called these hormones prolan A and prolan B.

The *testes* produce spermatozoa and the interstitial cells produce an internal secretion, which some investigators claim controls the development of secondary sex characteristics in the male and probably increases muscular strength.

The tendency of both sexes to become obese after castration is interpreted as evidence that the internal secretions of the gonads assist in regulating metabolic processes.

The liver. — In addition to other functions the liver forms two substances, *i.e.*, glycogen and urea, from materials which it takes from the blood and which are subsequently returned to the blood. The glucose brought to the liver by the portal blood is stored in the liver cells in the form of glycogen (animal starch) and when needed is again converted to glucose. The chief end-product of the metabolism of protein food, *i.e.*, urea, is eliminated by the kidneys. There is much evidence that urea is formed in the liver. The precursor of urea is ammonium carbonate which the liver cells convert into urea. These processes are examples of internal secretions.

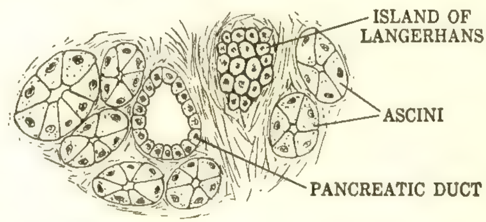


FIG. 196. — DIAGRAM OF THIN SECTION OF A BIT OF THE PANCREAS, HIGHLY MAGNIFIED.

The pancreas. — The pancreas forms an external secretion, the pancreatic fluid, but special groups of cells in the pancreas called the islands of Langerhans furnish an internal secretion containing *insulin* which is essential for the normal course of sugar metabolism.

Internal secretion of the gastric and intestinal mucous membrane. — The mucous membrane lining the pyloric end of the stomach contains some cells which secrete a hormone known as *gastrin.* This is carried by the blood to the peptic and pyloric glands which manufacture gastric fluid, and stimulates secretion. The mucous membrane of the intestine, particularly the duodenum, contains cells which secrete a substance known as *prosecretin,* which is inactive until the medium is acid. When the acid chyme from the stomach enters the duodenum, prosecretin is liberated, changed to *secretin,* absorbed by the blood, and carried to the pancreas liver, and intestines, stimulating each organ to secretory activity.

Endocrine balance. — The study of the internal secretions has made it evident that the effect of certain secretions is to reinforce each other, and to some extent they are able to substitute for each

other. Examples are the thyroid and the pituitary which stimulate metabolism. Some of the cells of the gonads might also be classed with the pituitary and the thyroid because they also stimulate metabolism. Instead of reinforcing each other, certain secretions act in directly opposite ways, *e.g.*, insulin favors the formation of glycogen, and epinephrin favors its change into simple sugar. This has led to much discussion regarding the classification of endocrines and the so-called *endocrine balance.* The idea of endocrine balance is correct if it is meant to indicate that each ductless gland has an optimum rate of activity which varies in accordance with the requirements of the body; but is incorrect if it is meant to indicate that most of the endocrines are antagonistic and are balanced against each other.

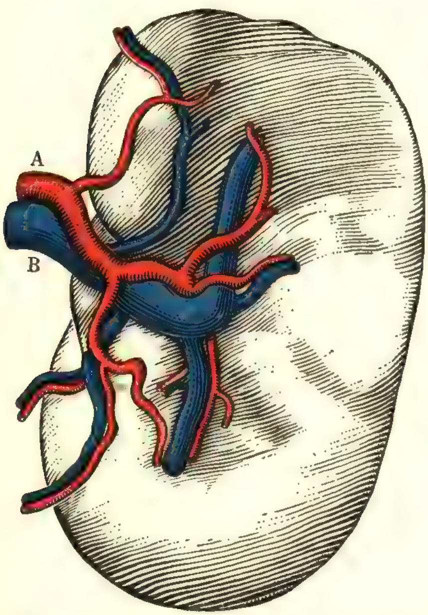


FIG. 197. — THE SPLEEN, SHOWING THE GASTRIC AND RENAL SURFACES AND THE BLOOD-VESSELS. *A*, lienal or splenic artery. *B*, lienal or splenic vein. (Gerrish.)

The spleen (lien).—Some authorities class this organ with the ductless glands and others class it with the lymph-nodes. It is situated directly beneath the diaphragm, behind and to the left of the stomach. It is bean-shaped, convex on the outer surface, concave on the inner. It is covered by peritoneum, and held in position by two folds of this membrane. Beneath the serous coat it is covered by a fibrous coat containing white fibrous tissue, yellow elastic tissue, and muscle fibers. From this coat trabeculæ run into the spleen substance and form a framework which supports arterioles. Where the blood-vessels branch, are found masses of lymphoid tissue, which are called Malpighian[10] follicles. In the medulla or pulp of the spleen are large branching cells in the meshwork of which are the various forms of white cells, red cells,

[10] Marcello Malpighi (1628–1694), a physician and professor of comparative anatomy at Bologna.

and large rounded cells called splenic cells, which are capable of ameboid movement, and often contain pigment and red blood cells in their interior.

Blood-supply. — Blood is supplied to the spleen by the lienal (splenic) artery, a branch of the celiac artery. It divides into six or more branches, which enter the concave side of the spleen at a depression called the hilum. The arrangement of the blood-vessels is peculiar to this organ. After entering, the arteries divide into many branches and terminate in tufts of arterioles, which open freely into the splenic pulp.[11] The blood is collected from the pulp by thin-walled veins, which unite to form the lienal vein. The lienal vein unites with the superior mesenteric to form the portal tube and carries the blood to the liver.

Functions. — The most important facts known about the spleen are the slow expansion and contraction of the organ, which occurs during digestion. After a meal the spleen increases in size and reaches a maximum about the fifth hour of digestion. Then it slowly decreases to its former size. The significance of this with reference to the digestive processes is not understood. The distinctive function or functions of this organ are not known. It is usually credited with the following:

(1) The formation of red cells during fetal life and even after birth. It may even assume this function after severe anemia in the adult.

(2) One suggestion is that many of the leucocytes of the blood are derived from other leucocytes in the spleen, and that the lymphocytes are formed in the Malpighian follicles. Another suggestion is that the spleen acts as a reservoir of blood cells, and when conditions, such as exercise or hemorrhage, make more blood necessary, the contractions of the spleen expel the reserve.

(3) Large numbers of erythrocytes in various stages of disintegration are found in the spleen pulp, hence it is thought to help in the disintegration of red cells.

(4) The presence of a large amount of organic iron is taken to indicate that the spleen may play a part in the preparation of new hemoglobin, or the preservation of the iron set free in the disintegration of red cells.

(5) Various waste products that result from the metabolism of nucleoproteins are found in the liver and it is thought that the

[11] Organs which contain sinuses, into which the blood is poured, thus bringing the blood into intimate contact with the gland tissue, are called *hæmal glands.* The spleen is an example of a hæmal gland.

spleen changes these substances to uric acid which is excreted in the urine.

(6) Some observers claim that the spleen takes part in the production of antibodies and immune substances, and therefore plays a part in developing resistance to infections.

(7) It has also been suggested that the spleen gives rise to a substance (hormone) which stimulates the process of blood formation in the marrow.

SUMMARY

Coöperation, coördination, or **integration** of different systems of body

- **due to**
  1. Connections with nervous system which are maintained throughout body.
  2. Chemical products which are transferred from place to place by the blood.

- **Glands**
  - **Definition** — Glands are organs that form secretions.
  - **Essentials**
    - Epithelial cells which are active secreting agents.
    - Liberal blood-supply from which material for secretion is drawn.
    - A basement membrane which serves to hold the cells in position and carries nerve fibers.
  - **Stimuli** — Nervous or chemical origin.
  - **Classification according to structure**
    - Simple — tubular or saccular cavities — acini — open by one single duct.
    - Compound — many tubular or saccular cavities opening by small ducts into main duct.
  - **Secretions** — A new substance, the product of a gland, elaborated from the blood by cell action and intended for use in the body.
  - **Excretions** — Are secretions which are to be eliminated.
  - **Classified according to function**
    1. Secretory — form secretions
       1. Have ducts.
       2. Ductless or endocrine organs.
    2. Excretory — form excretions — have ducts.

External Secretions. — Glandular secretions which are carried to their destination by a duct. In other words secretions of glands with ducts.

- **Glands with Ducts**
  - Salivary glands, Gastric glands, Intestinal glands, The Pancreas, The Liver — furnish secretions which promote digestion.
  - Lacrimal or tear-glands, Tarsal glands of eyelids, Ceruminous glands of the ear, Sebaceous and sweat-glands of skin — moisten, lubricate, and protect surfaces on which discharged.
  - Mammary glands — milk for young of species.
  - The kidneys — eliminate waste.

- **Enzymes**
  - Digestive fluids owe their power to promote chemical reactions to **enzymes.**
  - **Definition** — Substances produced by living cells which act by catalysis.
  - **Characteristics**
    - Act best at body temperature.
    - Require medium of definite reaction.
    - Action is specific and may be reversible.
  - **Zymogen**
    - Antecedent or inactive form activated by
      - Activators — inorganic.
      - Kinases — organic.
  - **Co-enzymes** — Substances which help or act with an enzyme.

- **Internal Secretions or Endocrines**
  - **Definition** — Secretions formed by glands, which leave the glands by the blood or lymph.
  - **Function** — Contain autacoids which have the power to rouse to action or modify the action of some organ or organs.
  - **Autacoids** — drug-like principles produced in internal secreting tissues and organs
    - Hormones — stimulate activity.
    - Chalones — inhibit or depress activity.

- **Ductless Glands**
  - **Definition** — Glands that have no ducts.
  - **Function** — Intimately connected with purpose of endocrines which they produce.
  - **Methods of Study**
    - Observation of the conditions caused by disease of these glands.
    - Various experiments, feeding of glands, of various extracts, and active principles.
    - Subcutaneous or intravenous injection of glandular extracts.
  - The Thyroid.
  - The Parathyroids.
  - The Thymus.
  - The Suprarenal glands or adrenals.
  - The Pituitary or Hypophysis.
  - The Pineal body or Epiphysis.
  - Gonads
    - The Testes — male.
    - The Ovaries — female.

- **Endocrine balance**
  - Indicates that each ductless gland has an optimum rate of activity which varies in accordance with the requirements of the body.

- **Spleen**
  - Sometimes classed with ductless glands, sometimes with lymph-nodes.
  - **Description**
    - Beneath diaphragm, behind and to the left of the stomach.
    - Bean-shaped, convex on outer surface, concave on inner.
    - Consists of a fibrous network filled with a vascular pulp, enclosed in a fibrous and muscular capsule which is covered by peritoneum.
    - Blood supplied by lienal artery (branch of celiac), divides into six or more branches which enter hilum.
    - Blood supply peculiar — arteries — veins, no connecting capillaries.

Spleen	Functions	Not definitely known. Credited with the following: 1. Formation of red cells during fetal life and after birth if need arises. 2. Leucocytes of blood may be derived from leucocytes of spleen. Lymphocytes may be formed in the Malpighian follicles. Spleen may act as reservoir of blood cells and when necessary may expel the reserve. 3. Helps in disintegration of red cells. 4. May play a part in preparation of hemoglobin, or preservation of iron. 5. Changes waste products of nucleoproteins to uric acid, which the kidneys can excrete. 6. May take part in the production of antibodies and immune substances. 7. May give rise to a substance (hormone) which stimulates the process of blood formation in the marrow.

NAME OF GLAND	LOCATION	SECRETION	PROBABLE FUNCTION	DISEASES ASSOCIATED WITH IT
Thyroid Small gland. Weighs about one ounce Consists of two lobes connected by an isthmus	Placed in front of trachea below thyroid cartilage	*Thyroxin* formula, ($C_{15}H_{11}O_4NI_4$) contains 65% of iodine	Influences the general rate of oxidation in the body	**Hypothyroidism**: Goiter — morbid enlargement. Cretinism — species of idiocy, due to congenital defect of thyroid or atrophy in early life. Myxedema — due to atrophy of thyroid in adult life. **Hyperthyroidism**: Graves' disease or exophthalmic goiter.
Parathyroids Four small glands	Between the posterior borders of the lobes of the thyroid gland and its capsule.	Parathyroid secretion.	Produce a hormone that regulates the blood calcium level	When the parathyroids are removed **tetany** develops. **Hyperparathyroidism**: Muscular weakness. High blood calcium.
Thymus Consists of two lateral lobes which occasionally unite to form a single mass Temporary organ Reaches greatest size at puberty	Upper part of chest cavity, along the trachea and overlapping the great blood-vessels as they leave the heart.	Thymus secretion	Experimental results are contradictory. May be starting point of lymphoid tissue. Other theories are concerned with removal of excess of guanidine from blood, and regulation of calcium content of blood. Has been credited with inhibiting growth of sex glands.	**Status Lymphaticus** is characterized by enlargement and over-activity of the thymus and enlargement of the lymphoid structures in general.

Name of Gland	Location	Secretion	Probable Function	Diseases Associated with It
Suprarenal bodies or adrenals Two small glands, each surrounded by a fibrous capsule and consist of two parts { Cortex, Medulla	Placed above and in front of the upper end of each kidney			Removal of these glands causes death. Symptoms preceding death similar to **Addison's disease.**
Cortex consists of epithelial cells arranged in columns. These cells are derived from the part of the mesoderm that gives rise to the kidneys.		Cortical Secretion	Nature and function of cortex require further investigation	
Medulla consists of a network of large granular cells which when treated with chromic acid give a yellow or brown reaction. Derived from neural crest of ectoderm		*Medulla-Epinephrin*	Constitutes a reserve mechanism that comes into action at times of stress. Epinephrin augments the response of sympathetic nerves, increases the heart beat, increases blood-supply to muscles, nervous system, and heart, and increases output of glucose from liver.	
Pituitary or Hypophysis Mass of reddish gray tissue about 1 cm. in diameter. Consists of an anterior and posterior lobe and a tuberal part containing colloid	Lodged in the sella turcica of the sphenoid bone	Posterior lobe—*Pituitrin* or *hypophysin*	1. Pressor effect — blood-pressure raised and heart rate slowed 2. Stimulates contraction of visceral muscle 3. Oxytocic effect. Contraction of muscles of uterus 4. An increased secretion of urine followed by decreased secretion 5. Galactogogic effect	Injury results in polyuria, glycosuria, loss of heat regulation, and early death. **Diabetes insipidus** is a disease of the pituitary gland or of the structures at the base of the brain in this region.

NAME OF GLAND	LOCATION	SECRETION	PROBABLE FUNCTION	DISEASES ASSOCIATED WITH IT
		Anterior lobe — *Tethelin*	Feeding of extracts seems to cause more rapid growth in height	It is claimed that abnormalities in growth of the skeleton are related to an enlargement and hypersecretion of this lobe. **Gigantism** in early life. **Acromegaly** in later life.
Pineal Body or Epiphysis Reddish gray body about 8 mm. in length, develops as an outgrowth of third ventricle of brain	Attached to roof of third ventricle of brain		Thought to furnish secretion that inhibits growth and development of the reproductive organs	Tumors of the pineal gland sometimes develop in children. In boys the brain symptoms are associated with precocious development of sex organs, and precocious physical and mental development.
Gonads — *Ovaries* Two almond-shaped bodies which weigh from 2 to 3.5 gm.	One on each side of the uterus, attached to the back of the broad ligament behind and below the uterine tubes	*Œstrin* or *Theelin* is formed by vesicular follicles	Seems to act by maintaining nutrition and mature size of female reproductive organs	Excessive ovarian function produces precocious puberty. Diminished ovarian function characterized by late onset of menstruation, faulty development of genital organs, delayed menstruation, etc.
		Luteal hormone is formed by cells of corpus luteum.	Sensitizes the mucous membrane of the uterus so that it responds to the contact of the developing ovum and assists in implantation	
Testes Two glandular organs which weigh from 10.5 to 14 gm.	In the scrotum		Some investigators claim that the internal secretion produced by the interstitial cells of the testes controls the development of secondary sex characteristics in the male and probably increases muscular strength	The tendency of both sexes is to become obese after castration.

NAME OF GLAND	LOCATION	SECRETION	PROBABLE FUNCTION	DISEASES ASSOCIATED WITH IT
Liver Largest gland in body, weighs from 42 to 56 ounces	Under the diaphragm on right side		1. Changes glucose to glycogen and glycogen to glucose 2. Changes ammonium carbonate to urea	
Pancreas A compound gland which weighs between two and three ounces	In front of the first and second lumbar vertebræ behind the stomach	Islands of Langerhans furnish an internal secretion containing *Insulin*.	1. Restores the power to utilize the glucose of the blood 2. Accelerates the synthesis of sugar to glycogen and the storage of glycogen 3. Restricts production of sugar in liver from protein and fat 4. Counteracts the tendency to acidosis	**Diabetes Mellitus** See Chap. XX.
Gastric Mucosa	Stomach	*Gastrin* is hormone of internal secretion.	Carried by blood to fundic and pyloric glands and stimulates secretion	
Intestinal Mucosa	Intestine-duodenum	Cells of duodenum contain *prosecretin*, changed by acid to *secretin*.	Secretin stimulates the pancreas, liver, and intestines to activity.	

CHAPTER XVII

RESPIRATORY SYSTEM: RESPIRATION; RESPIRATORY PHENOMENA

All living things require oxygen for their vital processes. The normal course of all the chemical changes in the tissue cells is dependent upon oxygen, hence the need of a continual supply. One of the end-products of these chemical changes is carbon dioxide, hence the need for continual elimination of carbon dioxide. In unicellular animals the intake of oxygen and the output of carbon dioxide occur at the surface of the cell. As organisms increase in size and complexity, some form of apparatus is developed whose function consists in bringing air or oxygen-laden water to all the cells of the organism. In man the circulating blood is brought into contact with the air in the lungs, where it takes up oxygen and gives up carbon dioxide, and later with the cells in the tissues, where it gives up oxygen and takes up carbon dioxide.

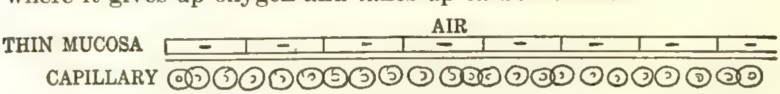


FIG. 198. — DIAGRAM OF THE ESSENTIALS OF A RESPIRATORY SYSTEM. (Gerrish.)

This exchange of gases is known as respiration and is dependent upon the proper functioning of certain organs which we group together and call a *respiratory system*. The essentials of a respiratory system consist of a moist and ~~permeable~~ membrane, with a moving stream of blood containing a relatively high percentage of carbon dioxide on one side, and air or fluid containing a relatively high percentage of oxygen on the other. In most aquatic animals the respiratory organs are external in the form of gills; in mammals the respiratory organs are situated internally in the form of lungs. In man the lungs are placed in communication with the nose and mouth by means of the bronchi, trachea, and larynx.

NOSE

The nose is the special organ of the sense of smell, but it also serves as a passageway for air going to and from the lungs. It

filters, warms, and moistens the entering air, and also helps in phonation. It consists of two parts, — the external feature, the nose, and the internal cavities, the nasal fossæ.

The external nose is composed of a triangular framework of bone and cartilage, covered by skin and lined by mucous membrane. On its under surface are two oval-shaped openings — the nostrils (anterior nares) — which are the external openings of the nasal

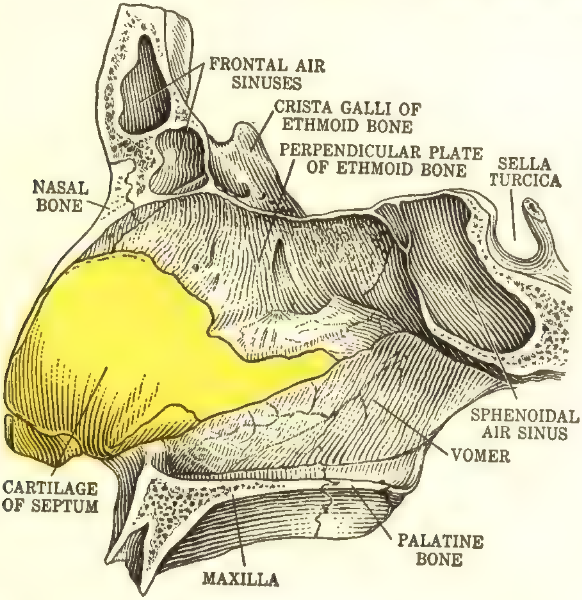


FIG. 199. — BONES AND CARTILAGE OF SEPTUM OF NOSE. Left side.

cavities. The margins of the nostrils are usually provided with a number of hairs.

The nasal cavities are two wedge-shaped cavities, separated from one another by a partition, or septum. The septum is formed in front by the crest of the nasal bones and the frontal spine; in the middle, by the perpendicular plate of the ethmoid; behind, by the vomer and sphenoid; below, by the crest of the maxillæ and palatine bones. The septum is usually bent more to one side than the other, a condition to be remembered in giving nasal treatments.

The conchæ and processes of the ethmoid, which are exceedingly light and spongy, project into the nasal cavities, and divide them into three incomplete passages from before backwards, — the superior, middle, and the inferior meatus. The palate and maxillæ separate the nasal cavities from the mouth, and the horizontal

plate of the ethmoid forms the partition between the cranial and nasal cavities.

The nasal cavities[1] communicate with the air in front by the anterior nares, while behind they open into the nasal part of the pharynx by the two posterior nares (choanæ). They are lined by mucous membrane, the upper layer of which is ciliated epithelium. This membrane, which is highly vascular, is continuous externally with the skin, and internally with the mucous membrane lining the sinuses and other structures connected with the nasal passages. Inflammatory conditions of the nasal mucous membrane may extend into the sinuses.[2]

Advantage of nasal breathing. — Under normal conditions breathing should take place through the nose only (1) because the arrangement of the conchæ makes the upper part of the nasal passages very narrow; (2) these passages are thickly lined, and freely supplied with blood which keeps the temperature relatively high and makes it possible even in the coldest weather to moisten and warm the air before it reaches the lungs; and (3) the presence of hairs at the entrance to the nostrils and the cilia of the epithelium serve as filters to arrest the passage of dust or other foreign substances which might be carried in with the inspired air.

Nerves and blood-vessels. — The mucous membrane of the septum contains the endings of the olfactory nerve. ~~The nerves for the muscles of the nose are branches of~~ the facial (seventh cranial), an~~d the~~ skin receives branches from ~~the~~ ophthalmic and maxillary n~~erves,~~ which are branch~~es of the trigeminal~~ (fifth ~~cranial~~). Blood is supplied to the external nose by branches from the external and internal maxillary arteries, which ~~are derived from~~ the external carotid. The ~~lateral~~ walls and the septum of the nasal cavities are supplied with nasal branches of the ethmoidal arteries, which ~~are derived~~ from the internal carotid.

The mouth serves as a passageway for the entrance of air, and the pharynx transmits the air from the nose or mouth to the larynx,

[1] Eleven bones enter into the formation of the nasal cavities: the floor is formed by the palatine (2) and part of the maxillæ bones (2); the roof is formed chiefly by the horizontal plate of the ethmoid bone (1), the sphenoid (1), and by the small nasal bones (2); in the outer walls we find, in addition to processes from other bones, the two conchæ (2). The vomer (1) forms part of the septum.

[2] One reason for the emphasis on the prevention or early cure of head colds is due to this possibility. The infection may spread upward into the nasolacrimal duct, lacrimal sac, and conjunctiva; or into the head sinuses, such as the frontal, ethmoidal, sphenoidal, or the antrum of Highmore; or through the pharynx into the larynx, trachea, and bronchi; or it may spread through the Eustachian tube to the middle ear and the mastoid portion of the temporal bones. Perhaps the most serious possibility is the extension of the infection to the meninges by way of the olfactory nerve.

but both are closely associated with digestion and will be described with the digestive organs.

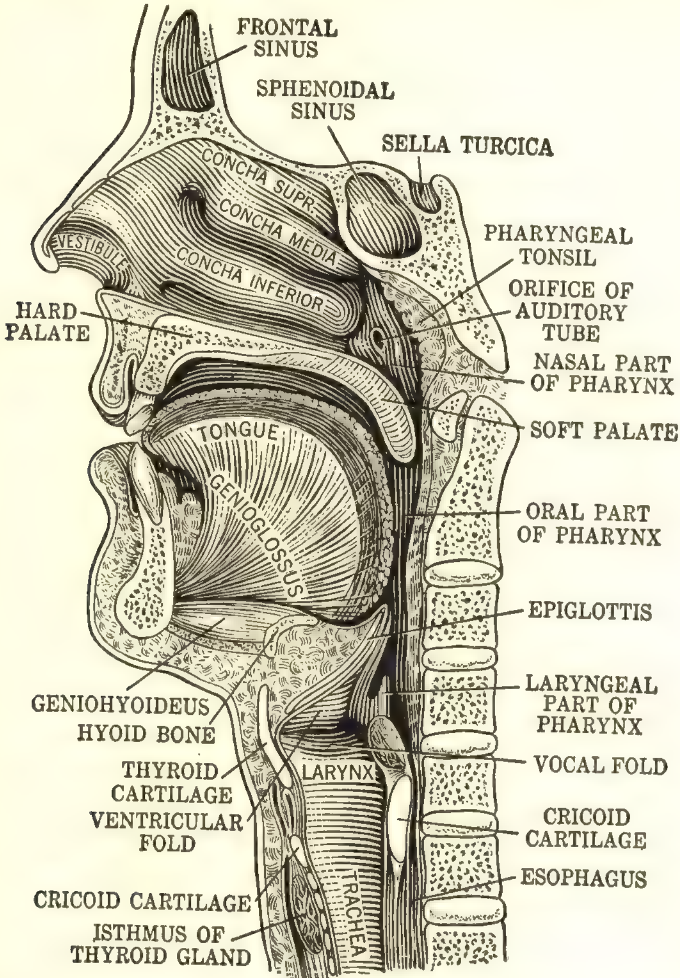


FIG. 200. — SAGITTAL SECTION OF THE NOSE, MOUTH, PHARYNX, AND LARYNX

RESPIRATORY SYSTEM

The respiratory system is composed of the following organs in addition to the nose, which has already been described.

1. Larynx. 2. Trachea. 3. Bronchi. 4. Lungs.

The larynx. — The larynx, or organ of voice, is placed in the upper and front part of the neck, between the root of the tongue

and the trachea. Above and behind it lies the pharynx, which opens into the esophagus, or gullet, and on either side of it lie the great vessels of the neck. The larynx is broad above and shaped somewhat like a triangular box, with flat sides and prominent ridge in front. Below it is narrow and rounded where it blends with the trachea. It is made up of nine pieces of fibro-cartilage, united by extrinsic and intrinsic ligaments, and moved by numerous muscles.

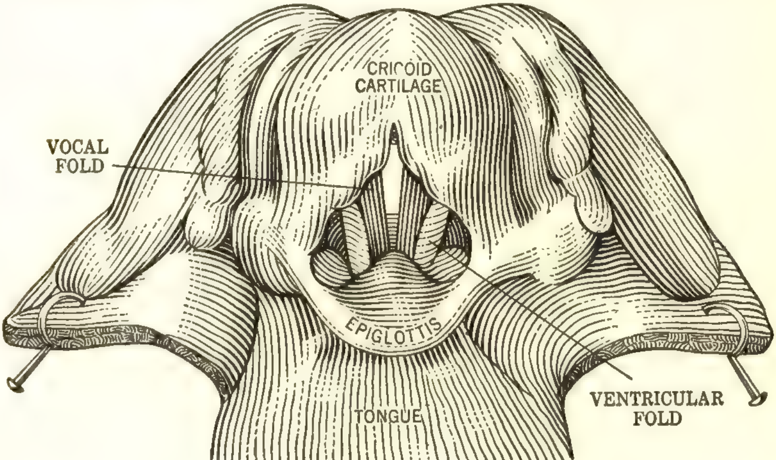


FIG. 201. — LARYNX. Viewed from above. (Gerrish.)

The three principal cartilages are the *thyroid*, *cricoid*, and *epiglottis*. The thyroid resembles a shield and is the largest. It rests upon the cricoid and consists of two square plates, or laminæ (right and left), which are joined at an acute angle in the middle line in front and form by their union the laryngeal prominence (Adam's apple).

The cricoid resembles a seal ring with the hoop part in front and the signet part in the back. The epiglottis is shaped like a leaf. The stem is inserted in the notch between the two plates of the thyroid. The larynx is lined throughout by mucous membrane, which is continuous above with that lining the pharynx, and below with that lining the trachea.

The cavity of the larynx is divided into two parts by two folds of mucous membrane stretching from front to back, but not quite meeting in the middle line. They thus leave an elongated fissure or chink, called the *glottis*, which is the narrowest segment of the air passages. The glottis is protected by the leaf-shaped lid of fibrocartilage, called the epiglottis

The vocal folds. — Embedded in the mucous membrane at the edges of the slit are fibrous and elastic ligaments, which strengthen the edges of the glottis and give them elasticity. These ligamentous bands, covered with mucous membrane, are firmly attached at either end to the cartilages of the larynx, and are called the inferior or *true vocal folds,* because they function in the production of the voice. Above these folds are two ventricular folds, which do not function in the production of the voice but serve to keep the true vocal folds moist, in holding the breath, and in protecting the larynx during the swallowing of food.

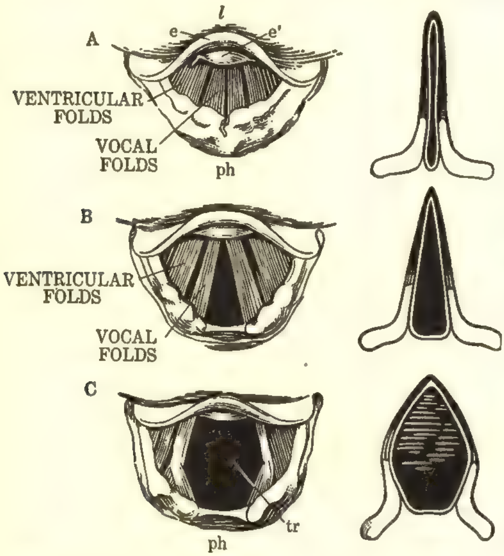


Fig. 202. — The Larynx as Seen by Means of the Laryngoscope in Different Conditions of the Glottis. *A*, while singing a high note; *B*, in quiet breathing; *C*, during a deep inspiration; *l*, base of tongue; *e*, upper free edge of epiglottis; *e′*, cushion of the epiglottis; *ph*, part of anterior wall of pharynx; *tr*, the trachea.

The glottis varies in shape and size, according to the action of muscles upon the laryngeal walls. When the larynx is at rest during quiet breathing, the glottis is V-shaped; during a deep inspiration it becomes almost round, while during the production of a high note the edges of the folds approximate so closely as to leave scarcely any opening at all.

Nerves and blood-vessels. — The laryngeal nerves are derived from the internal and external branches of the superior laryngeal, which leaves the vagus in the neck. Blood is supplied to the larynx by means of branches from the superior thyroid, which arises from the external carotid artery, and from the inferior thyroid, a branch of the thyroid axis, which arises from the subclavian artery.

Phonation. — This term is applied to the production of vocal sounds. All of the respiratory organs function in the production of vocal sounds, but the vocal folds, the larynx, and the parts above are specially concerned. The speech centers and parts of the brain

which control the movements of the tongue and jaw, also the tongue itself, are of special importance. The organs of phonation in man are similar to those of many animals much lower in the scale of life, but the association areas of the brain account for the greater variety of sounds that man can produce.

Voice. — The vocal folds produce the voice. A blast of air, driven by an expiratory movement out of the lungs, throws the two elastic folds into vibrations. These impart their vibrations to the column of air above them, and so give rise to the sound which we call the voice. The pharynx, mouth, and nasal cavities above the glottis act as resonating cavities. The volume and force of the expiratory blast and the amplitude of the vibrations of the vocal folds determine the loudness or intensity of the voice. The pitch of the voice depends upon the number of vibrations occurring in a given unit of time. This in turn is dependent on the length, thickness, and degree of elasticity of the vocal folds, and the tension by which they are held. When the folds are tightly stretched and the glottis almost closed, the highest sounds are emitted.

Differences between the male and female voice. — The size of the larynx varies in different individuals and this is one reason for differences in pitch. At the time of puberty, the growth of the larynx and the vocal folds is much more rapid and accentuated in the male than in the female. The increase in the size of the larynx causes an increase in the length of the vocal folds, and also gives rise to what is commonly called Adam's apple. These changes in structure are accompanied by changes in the voice, which becomes deeper and lower. Before the characteristic adult voice is attained, there occurs what is described as a break in the voice, due to the inability of the individual to control the longer vocal folds.

The trachea. — The trachea, or windpipe, is a membranous and cartilaginous tube, cylindrical in shape, about 11.2 cm. ($4\frac{1}{2}$ in.) in length, and about 2 to 2.5 cm. (1 in.) from side to side. It lies in front of the esophagus and extends from the larynx on the level of the sixth cervical vertebra to the level of the upper border of the fifth thoracic vertebra, where it divides into two tubes, — the two bronchi, — one for each lung.

The walls are strengthened and rendered more rigid by rings of cartilage embedded in the fibrous tissue. These rings are C-shaped and incomplete behind, the cartilaginous rings being completed by bands of plain muscular tissue where the trachea is flattened and comes in contact with the esophagus. Like the larynx, it is lined by mucous membrane, and has a ciliated epithelium upon its inner

surface. The mucous membrane, which also extends into the bronchial tubes, keeps the internal surface of the air-passages free from impurities; the sticky mucus entangles particles of dust and other matters breathed in with the air, and the incessant movements of the cilia continually sweep this dirt-laden mucus upward and outward.

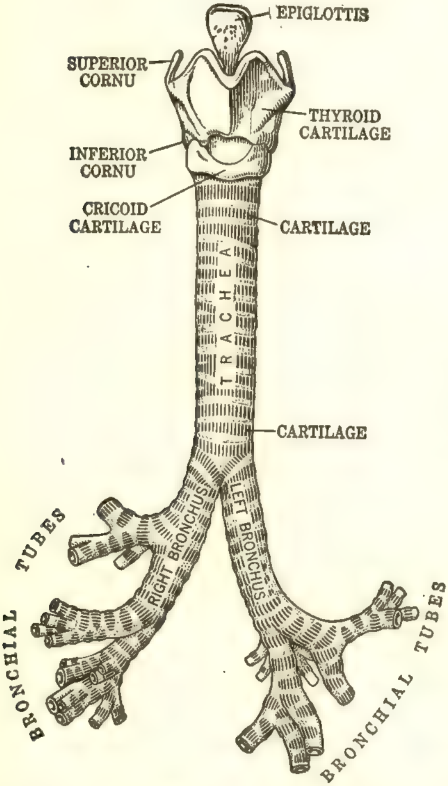


Fig. 203. — Front View of Cartilages of Larynx, Trachea, and Bronchi.

Nerves and blood-vessels of the trachea. — The nerves are derived from the vagus, the recurrent nerves, and from the thoracolumbar system. Blood is supplied to the trachea by the inferior thyroid arteries.

The bronchi. — The two bronchi, into which the trachea divides, differ slightly, the right bronchus being shorter, wider, and more vertical in direction than the left, which is longer and narrower. They enter the right and left lung, respectively, and then break up into a great number of smaller branches, which are called the bronchial tubes, or bronchioles. The two bronchi resemble the trachea in structure; but as the bronchial tubes divide and subdivide, their walls become thinner, the small plates of cartilage cease, the fibrous tissue disappears, and the finer tubes are composed of only a thin layer of muscular and elastic tissue lined by ciliated epithelium. Each bronchiole terminates in an elongated saccule called the atrium. Each atrium bears on all parts of its surface small, irregular projections known as alveoli or air cells. The lining of the walls of the alveoli consists of simple squamous epithelium.

LUNGS

The lungs (pulmones) are cone-shaped organs which occupy the two lateral chambers of the thoracic cavity and are separated from each other by the heart and other contents of the mediastinum. Each lung presents an outer surface which is convex, a base which is concave to fit over the convex portion of the diaphragm, and an apex which extends about 2.5–4 cm. (1–1½ in.) above the level of the sternal end of the first rib. Each lung is connected to the heart and trachea by the pulmonary artery, pulmonary vein, bronchial arteries and veins, the bronchus, plexuses of nerves, lymphatics, lymph-nodes, and areolar tissue which are covered by the pleura, and constitute the *root* of the lung. On the inner surface is a vertical notch called the **hilum,** which gives passage to the structures which form the root of the lung. Below and in front of the hilum there is a deep concavity, called the cardiac impression, to accommodate the heart. It is larger and deeper on the left than on the right lung, because the heart projects farther to the left side.

The **right lung** is the larger and heavier one; it is broader than the left, owing to the inclination of the heart to the left side; it is also shorter by an inch, in consequence of the diaphragm rising higher on the right side to accommodate the liver. The right lung is divided by fissures into three lobes, superior, middle, and inferior.

The **left lung** is smaller, narrower, and longer than the right. It is divided into two lobes, superior (upper) and inferior (lower).

Anatomy of the lungs. — The substance of the lungs is porous and spongy; owing to the presence of air it crepitates when handled, and floats in water. It consists of bronchial tubes and their terminal dilatations, numerous blood-vessels, lymphatics, nerves, and an abundance of fine, elastic, connective tissue binding all together. Each lobe of the lung is composed of many lobules, and into each lobule a bronchiole enters and terminates in an atrium. Each atrium presents a series of air cells or alveoli. In this way the amount of surface exposed to the air and covered by the capillaries is so immensely increased that it is estimated the entire inner surface of the lungs amounts to about 90 square meters, more than one hundred times the skin surface of the body.

Blood-vessels of the lungs. — Two sets of vessels are distributed to the lungs: (1) branches of the pulmonary artery, which bring blood to be aërated, and (2) branches of the bronchial arteries, which bring blood for nutritive purposes.

(1) The branches of the pulmonary artery accompany the bronchial tubes and form a plexus of capillaries around the alveoli. The walls of the alveoli consist of a single layer of simple squamous epithelium, surrounded by a fine, elastic connective tissue, and are exceedingly thin and delicate. Immediately beneath the layer of flat cells, and lodged in the elastic connective tissue, is this very close plexus of capillaries; and the air reaching the alveoli by the bronchial tubes is separated from the blood in the capillaries only by the thin membranes forming their respective walls. The

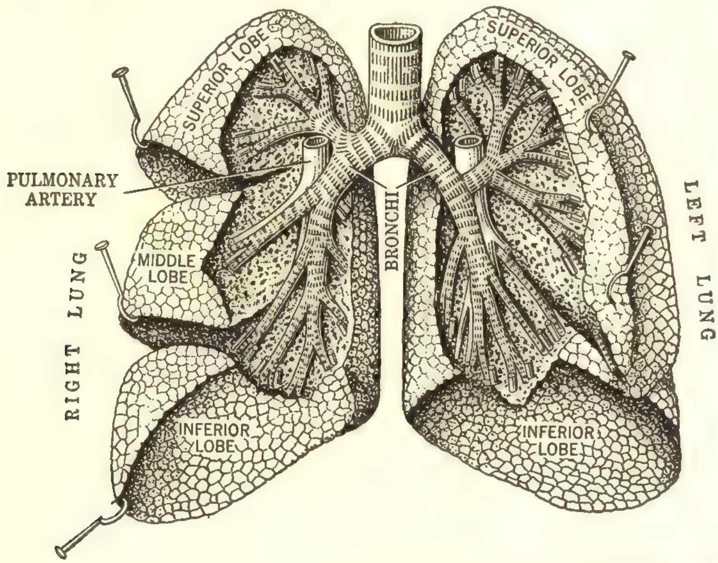


FIG. 204. — BRONCHI AND BRONCHIOLES. The lungs have been widely separated and tissue cut away to expose the air tubes. (Gerrish.)

pulmonary veins begin in the pulmonary capillaries, which coalesce to form larger branches. These run through the substance of the lung, communicate with other branches, and form larger vessels, which accompany the arteries and bronchial tubes to the hilum. Finally the pulmonary veins open into the left atrium.

(2) The branches of the bronchial arteries supply blood to the lung substance, — the bronchial tubes, coats of the blood-vessels, the lymph-nodes, and the pleura. The bronchial veins formed at the root of each lung receive veins which correspond to the branches of the bronchial arteries. Some of the blood supplied by the bronchial arteries passes into the pulmonary veins, but the greater

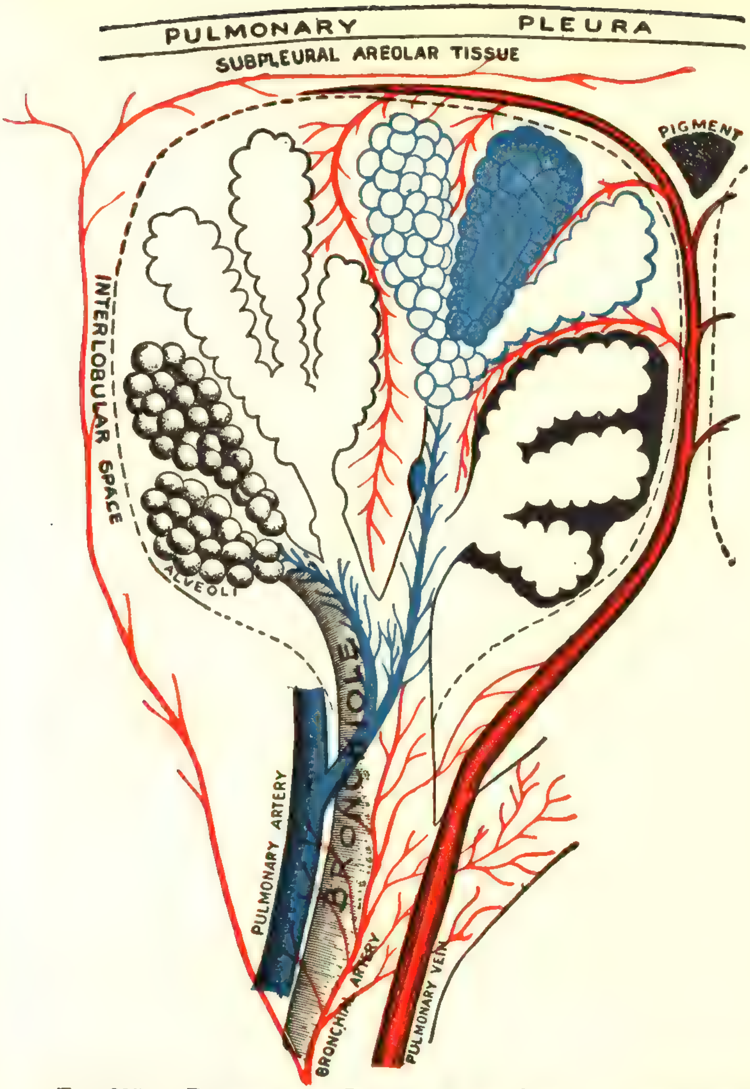


FIG. 205. — DIAGRAM OF A LOBULE OF THE LUNG. A bronchiole is seen dividing into two branches, one of which runs upward and ends in the lobule. In the lobule are four groups of atria. At the left are two atria, the alveoli or air cells of which present their outer surfaces. Next are three atria in vertical section, the alveoli of each opening into the common passageway. In the next group the first atrium shows a pulmonary arteriole surrounding the opening of each alveolus, and the second gives the same with the addition of the close capillary network in the wall of each alveolus. Around the fourth group is a deep deposit of pigment, such as occurs in old age, and in the lungs of those who inhale coal dust and the like. On the bronchiole lies a branch of the pulmonary artery (blue), bringing blood to the atria for aëration. Beginning between the atria are the radicles of the pulmonary vein (red). The bronchial artery is shown as a small vessel bringing nutrient blood to the bronchiole. (Gerrish.)

amount is returned to the bronchial veins. The right bronchial vein ends in the azygos vein, the left in the highest intercostal or hemiazygos vein.

Pleura. — Each lung is enclosed in a serous sac, the pleura, one layer of which is closely adherent to the walls of the chest and diaphragm (parietal); the other closely covers the lung (visceral or pulmonary). The two layers of the pleural sacs, moistened by serum, are normally in close contact, and the so-called pleural cavity is a potential rather than an actual cavity; they move easily upon one another, and prevent the friction that would otherwise occur between the lungs and the walls of the chest with every respiration. If the surface of the pleura becomes roughened as occurs in inflammation (pleurisy), more or less friction results and the sounds produced by this friction can be heard if the ear is applied to the chest. In health only a small amount of fluid is secreted and its absorption by the lymphatics almost keeps pace with its secretion, so that normally the amount of serum is very small. In pleurisy the amount may be considerably increased, due to the extra activity of the irritated secretory cells and excessive transudation from the congested blood-vessels. The amount may be sufficient to separate the two layers of the pleura, thus changing the potential plural cavity into an actual one.[3] This is known as pleurisy with effusion. If the effusion becomes purulent, it is called empyema.[4]

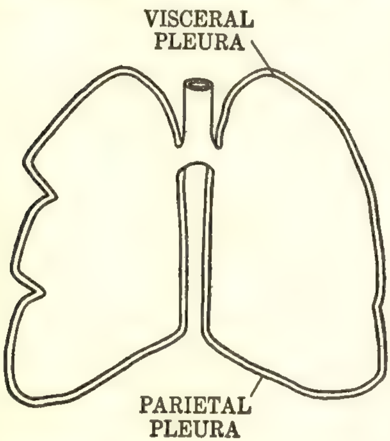


FIG. 206. — DIAGRAM SHOWING PARIETAL AND VISCERAL PLEURA.

The mediastinum, or interpleural space, lies between the right and left pleura in the median plane of the chest. It extends from the sternum to the spinal column and is entirely filled with the

[3] If a puncture is made through the chest walls so that air enters between the two layers of the pleura (pneumothorax), the lung will collapse. If the puncture is closed, the air will be gradually absorbed and the lung will resume its normal position.

Certain types of tuberculosis are treated by artificial pneumothorax. This is accomplished by surgical removal of part of the chest wall, or by injections of nitrogen into the chest cavity.

[4] The treatment of empyema is surgical. The usual operation is to remove a piece of rib in order to allow free drainage.

thoracic viscera, namely, the heart, aorta and its branches, pulmonary artery and veins, venæ cavæ, azygos vein, trachea, esophagus, thoracic duct, various veins, lymph-nodes, and nerves.

RESPIRATION

The main purpose of respiration is to supply the cells of the body with oxygen and rid them of the excess carbon dioxide which results from oxidation. It also helps to equalize the temperature of the body and get rid of excess water. To accomplish these purposes three processes are necessary:

(1) *Breathing.* — The process of breathing may be subdivided into inspiration or breathing in, and expiration or breathing out. Inspiration is a preliminary process whereby air is introduced into the lungs. Expiration is the process by which air is expelled from the lungs.

(2) *External respiration.* — This includes two processes: (*a*) external oxygen supply or the passage of oxygen from the alveoli of the lungs to the blood; and (*b*) external carbon dioxide elimination or the passage of carbon dioxide from the blood into the alveoli of the lungs.

(3) *Internal respiration.* — This also includes two processes: (*a*) internal oxygen supply or the passage of oxygen from the blood to the cells of the tissues; and (*b*) internal carbon dioxide elimination or the passage of carbon dioxide from the cells of the tissues to the blood.

It is evident that external respiration is a process which takes place in the lungs and internal respiration is a process which takes place in the cells that make up the tissues of the body.

The thorax is a closed cavity which contains the lungs. The lungs may be thought of as membranous sacs, the interior of which remains permanently open to the outside air by way of the bronchi. trachea, glottis, etc., while the outside is protected from atmospheric pressure by the walls of the chest.

During life the size of the thoracic cavity is constantly changing with the respiratory movements. When all the muscles of respiration are at rest, that is, at the end of a normal respiration, the size and position of the chest may be regarded as normal. Starting with this normal position, any enlargement constitutes active inspiration, the result of which is to force more air into the lungs. Following this active inspiration, the thoracic cavity may return passively to its normal position, giving a passive expiration, that is,

an expiration involving no muscular effort. Normal respiratory movements are of this type, an *active inspiration* followed by a *passive expiration.*

Mechanism of inspiration and expiration. — Active inspiration is the result of the contraction of the muscles of inspiration; passive expiration is due to the elastic recoil of the parts previously stretched. The thoracic cavity is enlarged in all directions: vertical, dorso-ventral, and lateral. The increase in the vertical diameter is brought about by the contraction of the diaphragmatic muscle, which draws the central tendon downward. The dorso-ventral and lateral diameters are increased by the contraction of the intercostal and other muscles which cause the sternum and ribs to move upward and outward. The lungs are expanded exactly in proportion to the increase in the size of the thorax. As in the heart, the atrial systole, the ventricular systole, and then a pause, follow in regular order; so in the lungs the inspiration, the expiration, and then a pause, succeed one another.

Muscles of inspiration. — The number of muscles used in inspiration varies greatly, depending on whether it is quiet or labored. The diaphragm and all the muscles that contract simultaneously with it are classed as inspiratory. Those that contract alternately are classed as expiratory. The following are the inspiratory muscles: (1) external[5] intercostals, (2) levatores costarum, (3) the scaleni,[6] (4) the sternocleidomastoid, (5) the pectoralis minor, and (6) the serratus posticus superior.[7] In forced inspirations the action of these muscles is supplemented by additional muscles of the trunk, larynx, pharynx, and face.

Muscles of expiration. — Normal expiration is considered a passive act due to gravity and the elastic recoil of the lungs. But in forced expirations diminution in the size of the thorax may be accomplished in two ways: (1) by forcing the diaphragm farther up into the thoracic cavity, a result obtained *not* by direct action of the diaphragm, but by contracting the muscular walls of the abdomen, the external and internal oblique, the rectus and the transversalis; and (2) by depressing the ribs. The muscles which depress the ribs are (1) the internal intercostals and (2) the trian-

[5] Some authorities find that the intercartilaginous portions of the internal intercostals are also inspiratory.

[6] Singular *scalenus*. There are three, scalenus anterior, scalenus medius, and scalenus posterior. They arise from the transverse processes of the cervical vertebræ, and are inserted in the first and second ribs.

[7] The serratus posticus superior extends from the spinous processes of the seventh cervical and upper two or three thoracic vertebræ to the upper borders of the second, third, fourth, and fifth ribs.

gularis sterni.[8] Some authorities add the (1) iliocostalis,[9] (2) serratus posticus inferior,[10] and (3) the quadratus lumborum, but it has not been definitely determined whether they act simultaneously with the diaphragm or alternately.

Types of respiration. — Two distinctive types of respiration are noted. The sequence of movements is the distinguishing factor. In the costal type the upper ribs move first and the abdomen second. The elevation of the ribs is the more noticeable movement. In the abdominal type, the abdomen bulges outward first, and this is followed by a movement of the thorax. Abdominal respirations are deeper. Restriction of the action of the diaphragm by tight clothing is thought to be the cause of costal respiration.

Respiratory center. — The respiratory center is located in the medulla oblongata. It is an automatic center, and is also sensitive to reflex stimulation from any of the sensory nerves. It has been demonstrated that the condition of the gases in the blood has a marked effect upon the activity of the center; the activity is increased in proportion to the venosity of the blood. In venous blood the carbon dioxide is increased and the oxygen is decreased. There is much evidence that either factor may act as a stimulus, but the accumulation of carbon dioxide is the more effective. It is generally believed that the carbon dioxide of the blood is the normal stimulus and acts as the main factor in *lung ventilation.* An increase in the concentration of carbon dioxide causes an increase in acidity or hydrogen-ion concentration, and it has been suggested that it is the hydrogen-ion concentration, rather than the increase in carbon dioxide itself, which acts as the normal stimulus. In this theory, it is assumed that the activity of the center is controlled by the hydrogen-ion concentration of the blood flowing through it, and this in turn varies with the pressure of carbon dioxide. This view has been accepted quite generally, although some investigators insist that carbon dioxide has a specific stimulating effect on the respiratory center independent of its effect in increasing the hydrogen-ion concentration. From the respiratory center, nerve impulses pass via the spinal cord and spinal nerve fibers to the intercostal muscles and the muscles

[8] Transversus thoracis or triangularis sterni is found on the front and inner side of the thoracic wall. Its fibers pass from the sternum running upward and outward to be inserted in the costal cartilages from the second to the sixth rib.

[9] The iliocostalis is one of the divisions of the sacrospinalis and is inserted into the inferior borders of the lower six or seven ribs.

[10] The serratus posticus inferior arises from the spinous processes of the lower two thoracic and upper second or third lumbar vertebra, and the insertion is in the inferior borders of the lower four ribs.

of the diaphragm, adjusting respiratory depth and rhythm to body needs. The respiratory rhythm is regulated also ~~reflexly~~ from the lungs themselves. Inspiratory movements start nerve impulses which reach ~~the~~ respiratory center over afferent fibers of the vagus nerves, inhibiting the center and ~~hence~~ bringing about expiratory movements. Pressure in the carotid sinus and aorta also reflexly affect respiratory rhythm.

Control of respiratory rate. — It is possible to increase or decrease the respiratory rate within certain limits, by voluntary effort,[11] for a short time, but this cannot be done continuously. If we intentionally arrest the respirations or diminish their frequency, the carbon dioxide tension in the blood increases and eventually the stimulus becomes too strong to be controlled. According to some observers, the "breaking point" is reached in 23 to 77 seconds. If, before holding the breath, several breaths of pure oxygen are taken, the breaking point may be postponed; or, if the lungs are thoroughly aërated by forced breathing, so that the carbon dioxide is forced out and pure oxygen is breathed in, the breaking point may be postponed as long as eight minutes.

Cause of the first respiration. — Normally the human fetus makes no respiratory movements while in the uterus. After birth and the interruption of the placental circulation, the first breath is taken. The immediate cause of this activity on the part of the respiratory center must be connected, if not identical, with the cause of the automatic activity of the center during life. Three views are held regarding the immediate cause: (1) that it is due to the increased amount of carbon dioxide in the blood, brought about by cutting the cord; (2) that it is due to stimulation of the sensory nerves of the skin, due to cooler air, handling, drying, etc.; and (3) that it is due to a combination of these causes.

If stimulation through the blood and stimulation through the nerves normally coöperate, it may be that the essential cause is the increased tension of the carbon dioxide, and therefore the increased concentration in hydrogen-ions, following the cutting of the cord.

During intrauterine life, the fetal blood is aërated so well by exchange with the maternal blood that it does not act as a stimulus to the fetal respiratory center.

Frequency of respiration. — The average rate of respiration for an adult is about sixteen to eighteen per minute. In health this

[11] In counting the respirations, it is desirable that it should be done without the patient's knowledge; otherwise the consciousness of being watched will cause an involuntary change in the rate and rhythm.

rate may be increased by muscular exercise, emotion, etc. Anything that affects the heart beat will have a similar effect on the respirations. Age has a marked influence. The average rate during the first year of life is about forty-four per minute, and at the age of five years, twenty-six per minute. It is reduced between the ages of fifteen and twenty-five to the normal standard.

External respiration. — This term is applied to the interchange of gases that takes place in the lungs. Once or twice each minute all the blood in the body passes through the capillaries of the lungs. This means that the time during which any portion of blood is in a position for respiratory exchange is only a second or two. Yet during this time, the following changes take place: (1) it loses carbon dioxide and moisture, (2) it gains oxygen, which combines with the reduced hemoglobin of the red cells and turns it into oxyhemoglobin, and as a result of this the crimson color shifts to scarlet; and (3) the temperature is slightly reduced.

It is helpful to compare the average amounts of oxygen and carbon dioxide found in the venous blood, and the amounts found in the arterial blood. Average figures for the dog are

	OXYGEN	CARBON DIOXIDE	NITROGEN
Venous blood contains..........	12%	45%	1.7%
Arterial blood contains.........	20%	38%	1.7%

For human blood the average figures given by different observers vary somewhat. The actual amounts of oxygen and carbon dioxide in venous blood vary with the nutritive activity of the tissues, and differ therefore in the various organs according to the state of activity of each organ, and the volume of its blood-supply. There is always a considerable amount of oxygen in venous blood, also a considerable amount of carbon dioxide in arterial blood. Consequently, the main result of the respiratory exchange is to keep the gas content of the arterial blood nearly constant at the figures given. Under normal conditions it is not possible to increase appreciably the amount of oxygen absorbed by the blood flowing through the lungs.[12]

[12] Student nurses sometimes find it difficult to reconcile this fact with the practice of using pure oxygen in critical cases of pulmonary disease. The relief of the pneumonia patient who inhales pure oxygen is usually marked because the blood absorbs an increased amount of oxygen. The reason for this seeming contradiction is that normal blood cannot absorb an increased amount of oxygen, but in the case of the pneumonia patient the composition of the blood as regards oxygen is below normal, and the inhalation of pure oxygen brings it up to the standard, hence the marked relief.

Physical laws of diffusion of gases. — The physical theory of respiration assumes that the passage of oxygen to and of carbon dioxide from the blood in the lungs, and the passage of oxygen from and of carbon dioxide to the blood in the tissues, takes place in accordance with the physical laws of the diffusion of gases. If two volumes of any gas, or two solutions of any gas at different pressures, are separated by a permeable membrane, the molecules of gas will pass through the membrane in both directions until the pressure is equal on both sides. The pressure of oxygen in the alveolar air is higher than in the venous blood, and the pressure of carbon dioxide is lower. The gases in the alveoli and in the blood-vessels are separated by the permeable membranes forming their respective walls. The diffusion of oxygen is from the alveolar air to the blood, and the diffusion of carbon dioxide is from the blood to the alveolar air. In the tissues the pressure conditions are reversed, and in consequence the diffusion of oxygen is from the blood to the tissues, and the diffusion of carbon dioxide is from the tissues to the blood. This may be represented as follows:

		Permeable Membrane	
Lungs	*Venous blood*		*Alveolar air*
	Oxygen	←	Oxygen
	Carbon dioxide	→	Carbon dioxide
Tissues	*Arterial blood*		*Tissues*
	Oxygen	→	Oxygen
	Carbon dioxide	←	Carbon dioxide

Oxygen, nitrogen, and carbon dioxide. — By far the greater portion of the oxygen in the blood is held in chemical combination with the hemoglobin of the red cells, while a smaller portion is held in solution in the plasma. When the pressure of oxygen in the surrounding medium falls sufficiently, oxyhemoglobin begins to dissociate, and free oxygen is given off. The process of dissociation is facilitated by increase of temperature, provided it does not rise to the point of coagulating the hemoglobin. The *nitrogen* in the blood is held in physical solution, and circulates without exerting any immediate effect upon the tissues.

Depending on whether the blood is arterial or venous, each 100 cc. contains from 45 to 55 cc. of carbon dioxide. A small amount (about 2 cc.) is held in physical solution. Perhaps as much as 20 cc. is contained in the plasma as carbonates, mainly sodium bicarbonate ($NaHCO_3$). It is thought that the remainder must be held in some form of chemical combination that undergoes some kind of reaction in the lungs and thereby releases carbon

dioxide. The nature of this combination and the carrier are still open questions, but there is some evidence to support the theory that the carbon dioxide combines with the alkali contained in the protein of the plasma and blood-cells, and that the hemoglobin plays an important part.

Capacity of the lungs. — After the lungs are once filled with air they are never completely emptied. In other words, no expiration ever completely empties the alveoli, neither are they completely filled. The quantity of air which a person can expel by a forcible expiration, after the deepest inspiration possible, is called the vital capacity, and averages about 3500 to 4000 cc.[13] (7–8 pts.) for an adult man. It is the sum of tidal, complemental, and supplemental air.

Tidal air designates the amount of air that flows in and out of the lungs with each quiet respiratory movement. The average figure for an adult male is 500 cc. (1 pt.).

Complemental air designates the amount of air that can be breathed in over and above the tidal air by the deepest possible inspiration. It is estimated at about 1600 cc. (3 pts.).

Supplemental air is the amount of air that can be breathed out after a quiet expiration by the most forcible expiration. It is equal to about 1600 cc.

Residual air is the amount of air remaining in the lungs after the most powerful expiration. This has been estimated on the cadaver and is about 1000 cc. (2 pts.).

Reserve air is the residual air plus the supplemental air in the lungs under condition of normal breathing, that is, about 2600 cc. (5 pts.).

Minimal air. — When the thorax is opened, the lungs collapse, driving out the supplemental and residual air, but before the alveoli are entirely emptied the small bronchi leading to them collapse, and entrap a little air in the alveoli. The small amount of air caught in this way is designated as minimal air.[14]

The inspired and expired air. — As the expirations never completely empty the lungs of air it follows that the air entering with each fresh breath becomes mixed with that in the alveoli. Consequently the air in the alveoli is never quite the same as inspired

[13] These figures are approximate:

16.386 cc. = 1 cu. in.; 568 cc. = 1 pt.; 8 pts. = 1 gal.

[14] Before birth the lungs are solid. If after birth respirations are made, the lungs do not collapse completely on account of the capture of minimal air. Whether or not the lungs will float has constituted one of the facts used in medico-legal cases to determine if a child was still-born. See W. H. Howell's *Textbook of Physiology*.

air, but normally the difference is not great. From a physiological standpoint the essential constituents of atmospheric air are oxygen, nitrogen, and carbon dioxide. In average figures the composition of inspired and expired air in volumes per cent is:

	Oxygen	Carbon Dioxide	Nitrogen
Inspired air	20.96%	0.04%	79%
Expired air	16.02%	4.38%	79%
	4.94 loss	4.34 gain	0

This table shows that in passing through the lungs, the air gains 4.34 volumes of carbon dioxide to each hundred and loses 4.94 volumes of oxygen. This is the main fact of external respiration. Three other changes occur.

1. However dry the external air may be, the expired air is nearly, or quite, saturated with moisture. An average of about one pint of water is eliminated daily in the breath.

2. Whatever the temperature of the external air, the expired air is nearly as warm as the blood; namely, of a temperature between 36.7° and 37.8° C. (98° and 100° F.). In man, breathing is one of the subsidiary means by which the temperature and the water contents of the body are regulated.

3. The heat required to warm the expired air and vaporize the moisture is taken from the body and represents a daily loss of heat. It requires about 0.5 large Calorie to vaporize a gram of water.

Ventilation. — Since at every breath the external air gains carbon dioxide and loses oxygen, it was formerly taught that the general discomfort, headache, and languor that result from sitting in a badly-ventilated room were due solely to the increase in carbon dioxide and the loss of oxygen. The results of many experiments seem to prove that the air in badly-ventilated rooms does not vary in oxygen and carbon dioxide content as much as had been supposed, though odors given off from the body and its clothing when present in any amount may affect the nervous system disagreeably. It is now thought that the injurious effects of remaining in a badly-ventilated room are due to interference with the heat-regulating mechanism of the body. Under favorable conditions the surface of the human body is kept comfortably cool by the air currents which pass over it and by the evaporation of perspiration. In a confined space there is a lack of movement of the air and it tends to become warm and humid. Moisture is

not taken from the skin promptly and the temperature rises. This results in a dilatation of the blood-vessels of the skin and an increased amount of blood is sent to the surface of the body, thereby increasing the unpleasant warmth. There is likely to be some reduction of the general blood-pressure leading to drowsiness or at least a feeling of inertia. Under such conditions the ability to do muscular work is diminished, mental efficiency is decreased, and fatigue comes on more quickly. In accordance with these views, the most effective precautions that can be taken to secure comfort in a room are to keep it cool and have some moisture and some movement of the air. It has been shown that starting an electric fan in a close room may relieve an almost intolerable condition as it favors the removal of heat from the bodies of the inmates and braces up their vasomotor systems. One writer suggests that the real difficulty with a stuffy room is that there is a lack of stimulation for the nervous system. One becomes relaxed and indolent because the nerve-endings in the skin are not being played upon as they would be by a constant change in environmental conditions. Because of these facts we are now taught that proper ventilation is based on many things. (1) There must be continuous movement of the air; (2) The temperature and degree of humidity must favor the evaporation of perspiration from the skin. Various experiments indicate that the temperature should approximate 18°–20° C. (65°–70° F.). Generally speaking, the higher the humidity the lower the temperature should be. (3) Odors from skin, clothing, light, and other sources must be eliminated. These requirements can only be met if the size of occupied rooms is in proportion (*a*) to the number of people occupying them; (*b*) to the facilities for ventilation; and (*c*) to the degree of air contamination likely to occur.

Internal respiration. — The exchange of gases in the tissues constitutes internal respiration and consists of (1) the passage of oxygen from the blood into the lymph, and from the lymph into the tissue cells, and (2) the passage of carbon dioxide from the tissue cells into the lymph, and from the lymph into the blood.

After the exchange of gases in the lungs, the aërated blood is returned to the heart, and distributed to all parts of the body. In passing through the capillaries the blood is brought into exchange with lymph, in which the oxygen pressure is low. The compound of oxygen and hemoglobin, oxyhemoglobin, is only stable in an environment where the oxygen pressure is relatively high. Consequently the blood in passing through the capillaries gives up

much of its oxygen, which passes to the lymph and from the latter to the tissue cells. On the contrary, the pressure of carbon dioxide is higher in the cells than in the blood, and this facilitates the passage of carbon dioxide from the cells to the lymph, and from the latter to the blood.

It is important to remember that the blood does not give up all its oxygen to the tissues, nor all of its carbon dioxide in the lungs. Excessive amounts of carbon dioxide will cause death by asphyxia, but in normal amounts it is as essential to life as oxygen.

RESPIRATORY PHENOMENA

Each intake of air is accompanied by a fine rustling sound which can be heard if the ear is applied to the chest wall. It is thought that the dilatation of the alveoli produces this sound, and absence of it indicates that the air is not entering the alveoli over which no sound is heard, or that the lung is separated from the chest wall by effused fluid. The air passing in and out of the larynx, trachea, and bronchial tubes produces a louder sound which is called a bronchial murmur. Normally this murmur is heard directly above or behind the tubes, but when the lung is consolidated as in pneumonia, it conducts sound more readily than usual and the murmur is heard in other parts of the chest. In diseased conditions the normal sounds are modified in various ways, and are then spoken of under the name of *râles*.

Eupnea. — This term is applied to ordinary quiet respiration made without obvious effort.

Dyspnea. — In its widest sense, *dyspnea* means any increase in the force or rate of the respiratory movements. These movements show many degrees of intensity corresponding with the strength of the stimulus. Usually the term *dyspnea* is reserved for the more labored breathing, in which the expirations are active and forced. Dyspnea may be caused by (1) stimulation of the sensory nerves, particularly the pain nerves; (2) an increase in the hydrogen-ion concentration of the blood; and (3) any condition that interferes with the normal rate of the respirations or of the heart action, or prevents the passage of air in or out of the lungs.

Hyperpnea. — The word *hyperpnea* is applied to the initial stages of dyspnea, when the respirations are simply increased.

Apnea. — The word means a lack of breathing. In physiological literature, it is used to describe the cessation of breathing movements due to lack of stimulation of the respiratory center, brought about by rapid and prolonged ventilation of the lungs. In medical literature, the term is sometimes used as a synonym for asphyxia or suffocation.

Cheyne-Stokes respirations. — This is a type of respirations which was first described by the two physicians[15] whose names it bears. It is an exaggeration of the type of respiration which is often seen during sleep in perfectly normal people. The respirations increase in force and frequency up to a certain point, and then gradually decrease until they cease altogether, and there is a short period of apnea, then the respirations recommence and the cycle is repeated. Cheyne-Stokes respirations are associated with conditions that depress the respiratory center, especially in brain, heart, and kidney diseases.

[15] John Cheyne, Scotch physician, 1777–1836. William Stokes, Irish physician, 1804–1878.

Edematous respiration. — When the air cells become infiltrated with fluid from the blood, the breathing becomes edematous and is recognized by the moist, rattling sounds, or râles, caused by the passage of the air through the fluid. It is a serious condition because it interferes with aëration of the blood and often results in asphyxia.

Asphyxia. — Asphyxia is produced by any condition that causes prolonged interference with the aëration of the blood, *viz.:* obstruction to the entrance

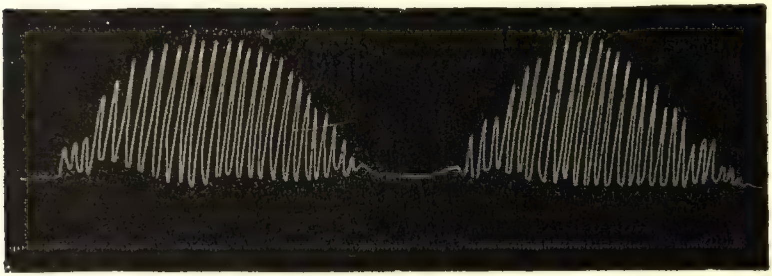


FIG. 207. — STETHOGRAPH TRACING OF CHEYNE-STOKES RESPIRATIONS IN A MAN. The time is marked in seconds. (Halliburton.)

of air to the lungs, depression of the respiratory center, an insufficient supply of oxygen, or a lack of hemoglobin in the blood. The first stages are associated with dyspnea and convulsive movements, then the respirations become slow and shallow and are finally reduced to mere twitches. The skin is cyanosed, the pupils of the eyes dilate, the reflexes are abolished, and respirations cease. If the heart continues to beat, resuscitation is often accomplished by artificial respiration, even after breathing has ceased.

SUMMARY

Respiration
- All living organisms require continual supply of oxygen.
- Chemical changes in tissue cells dependent upon it.
- Carbon dioxide is one end-product of chemical changes in cells, hence need for elimination of excess.
- Exchange of these gases in lungs and cells constitutes respiration.

Essentials of Human Respiratory System
- (1) Air containing a high percentage of oxygen on one side.
- (2) Moist and permeable membrane.
- (3) Moving stream of blood with a high percentage of carbon dioxide on other side.

~~Respiratory System~~
- Air ~~passes through~~ nose or mouth to
  - ~~1. Larynx.~~ ~~3. Bronchi.~~
  - 2. Trachea. 4. Lungs.

Nose — **Function** —
- Special organ of the sense of smell.
- Passageway for entrance of air to the respiratory organs.
- Helps in phonation.

Nose

- b. **External nose**
  - Framework of bone (nasal) and cartilage.
  - Covered with skin, lined with mucous membrane.
  - Nostrils are oval-shaped openings on under surface separated by a partition.
- c. **Internal cavities, or nasal fossæ**
  - Two wedge-shaped cavities.
  - Extend from nostrils to the pharynx.
  - Lined by mucous membrane, vascular and ciliated.
  - Formed by
    - 2 palatine.
    - 2 maxillæ.
    - 1 ethmoid.
    - 1 sphenoid.
    - 2 nasal.
    - 2 conchæ, and processes of the ethmoid
      - Superior meatus.
      - Middle meatus.
      - Inferior meatus.
    - 1 vomer.
    - —
    - 11 bones.
- **Advantages of nasal breathing**
  - Air
    - Warmed.
    - Moistened.
    - Filtered.
- **Communicating sinuses**
  1. Frontal.
  2. Ethmoidal.
  3. ~~Maxillary or antra of Highmore.~~
  4. Sphenoidal.
- d. **Nerves**
  1. Olfactory nerve — sense of smell.
  2. Facial nerve.
  3. Ophthalmic and maxillary.
- e. **Arteries**
  - External maxillary, Internal maxillary — derived from the external carotid.
  - Ethmoidal arteries derived from internal carotid.

2. **Larynx**

- Special organ of voice.
- Triangular box made up of nine pieces of cartilage.
- Situated between the tongue and trachea.
- Contains vocal folds.
- Slit or opening between cords called *glottis*, which is protected by leaf-shaped lid called epiglottis.
- Connected with external air by
  - Mouth.
  - Nose.
- b. **Nerves** — derived from
  - Internal branches of superior laryngeal.
  - External branches of superior laryngeal.
- **Arteries**
  - Superior thyroid, branch of external carotid.
  - Inferior thyroid, branch of thyroid axis.

Phonation

- **Phonation** — production of vocal sounds.
- **Organs of Phonation**
  - Respiratory organs.
  - Vocal folds — Lower pitch of male voice is due to greater length of vocal folds.
  - Larynx, pharynx, mouth, nose, and tongue.
  - Speech centers and parts of brain which control movements of the tongue and jaw, also association centers.

Trachea
- Membranous and cartilaginous tube, 4½ in. long.
- Strengthened by C-shaped rings of cartilage
  - Complete in front.
  - Incomplete behind.
- In front of esophagus.
- Extends from larynx to upper border of fifth thoracic vertebra, where it divides into two bronchi.
- **Nerves**
  - Branches of vagus.
  - Recurrent nerves.
  - Autonomics.
- **Arteries** — Inferior thyroid.

Bronchi and Bronchioles
- Right and left — structure similar to trachea.
- Right — shorter, wider, more vertical than left.
- Divide into innumerable bronchial tubes or bronchioles.
- As tubes divide their walls become thinner. Finer tubes consist of thin layer muscular and elastic tissue lined by ciliated epithelium.
- Each bronchiole terminates in elongated saccule called atrium (*infundibulum*).
- Each atrium bears on its surface small projections known as *alveoli,* or air cells.

Lungs
- **Location** — Lateral chambers of thoracic cavity, separated by structures contained in mediastinum.
- **Cone-shaped organs**
  - Outer surface convex to fit in concave cavity.
  - Base concave to fit over convex diaphragm.
  - Apex about an inch or an inch and one-half above the level of sternal end of first rib.
  - Hilum or depression on inner surface gives passage to bronchi, blood-vessels, lymphatics, and nerves.
- **Right** — Larger, heavier, broader, shorter — three lobes.
- **Left** — Smaller, narrower, longer — two lobes.
- **Anatomy**
  - Porous, spongy organs. Consist of bronchial tubes — atria — alveoli, also blood-vessels, lymphatics, and nerves held together by connective tissues.
- **Blood-vessels**
  - **Pulmonary artery**
    - Blood for aëration.
    - Accompanies bronchial tubes.
    - Plexus of capillaries around alveoli.
    - Returned by pulmonary veins.
  - **Bronchial arteries** — supply lung substance.

Pleura
- Closed sac — Envelops lungs, but they are not in it.
- Two layers
  - Pulmonary or Visceral — next to lung
  - Parietal — outside of visceral
  - Normally in close contact — potential cavity.
  - Moistened by serum.
- **Function** — to lessen friction.
- Pleurisy — inflammation of pleura.

Mediastinum
- Space between pleural sacs. Extends from sternum to spinal column. Contains the heart, large blood-vessels connected with heart, trachea, esophagus, thoracic duct, various veins, lymph-nodes, and nerves.

D

- **Respiration**
  - **Function**
    - Increase the amount of oxygen.
    - Decrease the amount of carbon dioxide.
    - Help to maintain temperature.
    - Help to eliminate waste.
  - 1. **Processes**
    - a **Breathing**
      - **Inspiration** — Process of taking air into lungs.
      - **Expiration** — Process of expelling air from lungs.
    - b **External Respiration**
      - External oxygen supply
      - External carbon dioxide elimination
      - } Takes place in the lungs.
    - c **Internal Respiration**
      - Internal oxygen supply
      - Internal carbon dioxide elimination
      - } Takes place in the cells.

- **Lungs**
  - May be regarded as membranous sacs.
  - Interior communicates with outside air by bronchi, trachea, glottis.
  - Outside protected by walls of chest.

- **Normal Respiratory Movements**
  - Normal size and position of chest is at end of normal respiration.
  - Active inspiration — Any enlargement which forces more air into lungs.
  - Passive expiration — Chest returns to normal, no effort involved.

- **Mechanism of Inspiration and Expiration**
  - **Enlargement of cavity**
    - Vertical.
    - Dorso-ventral.
    - Lateral.
  - **Inspiration**
    - Chest cavity enlarged
      - Elevation of ribs, dependent upon contraction of muscles of inspiration.
      - Descent of diaphragm by contraction of diaphragmatic muscles.
    - Enlargement of lungs — in proportion to enlargement of cavity — lungs in contact with chest walls.
    - Air rushes in through trachea and bronchi.
  - **Expiration**
    - Chest cavity made smaller
      - Inspiratory muscles relax.
      - Recoil of elastic thorax.
      - Recoil of elastic lungs.
    - Air forced out through trachea.

- **Muscles of Inspiration**
  - All the muscles that contract simultaneously with diaphragm.
  - The diaphragm.
  - The levatores costarum. }
  - The external intercostals. }
  - The scaleni. }
  - The sternocleidomastoid. } paired.
  - The pectoralis minor. }
  - The serratus posticus superior. }

Forced Expiration
- All the muscles that contract alternately with diaphragm. Size of chest cavity lessened. Accomplished in two ways:
  1. Force diaphragm farther up into thoracic cavity — Contraction of muscular walls of the abdomen, *i.e.* the external and internal oblique, the rectus and transversalis of both sides.
  2. Depress the ribs — paired.
     - Internal intercostals.
     - Triangularis sterni.
     - Some authorities add
       - Iliocostalis.
       - Serratus posticus inferior.
       - Quadratus lumborum.

Types of Respiration
- Sequence of movements is distinguishing factor.
- Costal — upper ribs move first, abdomen second.
- Abdominal — abdomen bulges outward first, followed by movement of thorax.
- Abdominal respirations are deeper.

Respiratory Center
- Located in medulla oblongata.
  - Center for inspiration is respiratory center.
  - Center for expiration — assumed.
- 2 Efferent fibers from respiratory center travel down spinal cord and ~~connect~~ with fibers of vagi and sympathetic nerves distributed in the lung tissue.
- 3 Afferent nerves lead to the respiratory center.
- Connection with the sensory fibers of all the cranial and spinal nerves assumed.
- Action
  - Automatic, *i.e.*, it is constantly sending impulses over afferent fibers.
  - Rate and rhythm dependent on
    - Vagi nerves — Two kinds of fibers:
      1. Inhibits inspiration.
      2. Inhibits expiration.
    - Chemical condition of blood, *i.e.*, hydrogen-ion concentration of the blood.

Control of Respiration
- Voluntary control for a short time.
- Breaking point reached in 23 to 77 seconds.
- If lungs are thoroughly aërated by forced breathing, breaking point may be postponed as long as eight minutes.

Cause of First Respiration
1. Due to increased amount of carbon dioxide in blood.
2. Due to stimulation of sensory nerves of skin.
3. Combination of these two causes.

Respiratory Rate
- 16 to 18 times per minute — influenced by
  - Muscular exercise.
  - Emotion.
  - Heart beat.
  - Age.

External Respiration
- Takes place in lungs.
- Blood
  - Loses about 7% of carbon dioxide.
  - Gains about 8% of oxygen
    - Oxyhemoglobin.
    - Scarlet color.
  - Temperature is slightly reduced.

Capacity of Lungs
- Exchange dependent on diffusion of gases.
- After lungs are once filled they are never emptied during life.
- Vital capacity — quantity of air person can expel by forcible expiration after deepest inspiration possible — averages from 3500 to 4000 cc.
- Terms in use
  - Tidal.
  - Complemental.
  - Supplemental.
  - Residual.
  - Reserve.
  - Minimal.

Inspired and Expired Air
- Changes effected
  1. Moisture increased. Expired air is saturated with moisture.
  2. Temperature increased. Expired air is as warm as blood.
  3. Heat to warm air and vaporized moisture taken from body.
  4. Oxygen decreased by 4.94%.
  5. Carbon dioxide increased by 4.34%.

Ventilation Requirements
1. Continuous movement of the air.
2. The temperature and degree of humidity must favor the evaporation of perspiration from the skin.
   The temperature should approximate 65° to 70° F. (18° C. to 20° C.). Generally speaking, the higher the humidity, the lower the temperature should be.
3. Disagreeable odors must be eliminated.

Internal Respiration
- Exchange of gases in the tissues.
- Consists of
  - Passage of oxygen from blood into lymph, and from lymph into cells.
  - Passage of carbon dioxide from tissue cells into lymph, and from lymph into blood.
- Important to remember blood does not give up all its oxygen to the tissues, nor all of its carbon dioxide in the lungs.

Respiratory Phenomena
- Air passing into alveoli produces a fine rustling sound.
- Air passing in and out of larynx, trachea, and bronchial tubes produces louder sound called bronchial murmur.
- In diseased conditions modified sounds are called *râles.*
- Eupnea — ordinary quiet respiration.
- Dyspnea — difficult breathing.
- Hyperpnea — excessive breathing.
- Apnea — lack of breathing.
- Cheyne-Stokes
  - Respirations increase in force and frequency, then gradually decrease and stop. Cycle repeated.
- Edematous — air cells filled with fluid, hence moist, rattling sounds.
- Asphyxia — oxygen starvation

CHAPTER XVIII

THE DIGESTIVE SYSTEM: ALIMENTARY CANAL AND ACCESSORY ORGANS

The foods which are eaten cannot be utilized by the cells of the body until they have been changed physically and chemically into such soluble substances as can diffuse into the blood-stream and be carried to all cells of the body and diffuse into them. Physical and chemical changes necessary to reduce varied foods to such standard substances as the tissues can use are effected in certain organs that compose the digestive system.

THE DIGESTIVE SYSTEM

The digestive system consists of the alimentary canal and the accessory organs: (1) tongue, (2) teeth, (3) salivary glands, (4) pancreas, and (5) liver.

Alimentary canal (digestive tube). — The alimentary canal is a continuous tube about 9 m. (30 ft.) long, which extends from the mouth to the anus. The greater part is coiled up in the cavity of the abdomen. From the esophagus to the rectum it is composed of four coats, from within outward:

(1) The **mucous** coat is a soft lining membrane containing glands which secrete digestive fluids.

(2) The **submucous** coat is composed of areolar connective tissue and serves to connect the mucous membrane to the parts beneath.

(3) The **muscular** coat consists almost entirely of non-striated muscular tissue, usually arranged in two layers. The cells of the internal layer are arranged circularly around the tube, and the cells of the external layer are longitudinal to it. The combined contractions of muscle cells arranged in this fashion produce a movement called a *peristaltic wave.*

The constricted portion of the tube is always preceded by an area that is relaxed, which renders the contraction more effective in forcing the contents onward.

(4) The esophagus is above the diaphragm and the outer coat is *fibrous.* Below the diaphragm the fourth coat is the serous coat, the outer layer of which is a part of the visceral peritoneum.

The peritoneum. — This is the largest serous membrane in the body. In the male it consists of a closed sac, the parietal layer of which lines the walls of the abdominal cavity, the inner or visceral layer being reflected over the abdominal organs, and the upper surface of some of the pelvic organs. The space between the

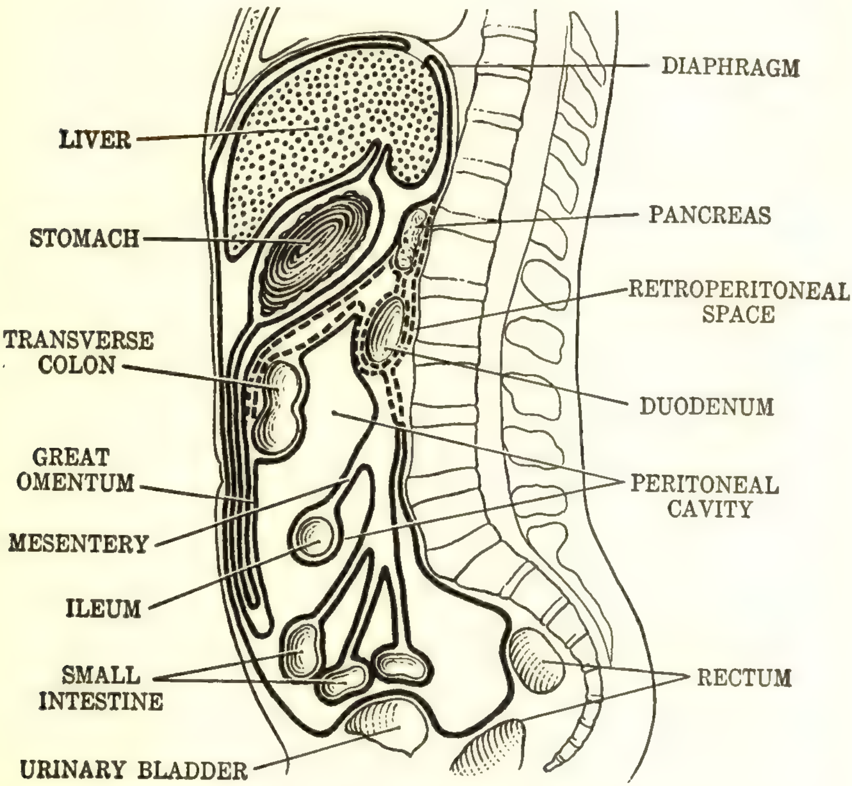


FIG. 208. — DIAGRAM OF A SIDE VIEW OF THE BODY, SHOWING ABDOMINAL CAVITY, PERITONEUM, MESENTERY, AND OMENTUM. The continuous lines indicate the free surfaces of the peritoneum, the dotted lines indicate those parts of the peritoneum in which the free surfaces have disappeared.

parietal and visceral layers is named the peritoneal cavity; but under normal conditions this cavity is potential, since the parietal and visceral layers are in contact. The arrangement of the peritoneum is very complex, for several elongated sacs and double folds extend from it, to pass in between and either wholly or partially surround the viscera of the abdomen and pelvis. One important fold is the *omentum*, which hangs like a curtain in front of the stomach and the intestines; another is the *mesentery*, which is a

continuation of the serous coat and attaches the small and much of the large intestine to the posterior abdominal wall.

When the abdominal cavity is opened, the intestines appear to lie within the cavity like a loose coil of rope. If, however, an attempt is made to lift a coil from its place, a clear, glistening sheet of tissue is found attached to it. This is the mesentery. The dorsal portion is gathered into folds which are attached to the dorsal abdominal wall along a short line of insertion. This arrangement gives the mesentery the appearance of a ruffle or flounce.

Functions of the peritoneum. — Like all serous membranes the peritoneum serves to prevent friction between contiguous organs by secreting serum which acts as a lubricant. To a limited extent it serves to hold the abdominal and pelvic organs in position, also unites and separates these organs. In addition to these functions, the omentum usually contains fat.

Divisions of the alimentary canal. — The alimentary canal has been given different names in different parts of its course. These names are:

Mouth cavity, containing tongue, orifices of ducts of salivary glands, and teeth.
Pharynx.
Esophagus.
Stomach.

Small or thin intestine	Duodenum. Jejunum. Ileum.	
Large or thick intestine	Cecum. Colon. → Rectum. Anal canal.	Ascending. Transverse or mesial. Descending. Sigmoid.

The mouth (buccal cavity). — The mouth is a nearly oval-shaped cavity bounded laterally and in front by the cheeks and lips; behind, it communicates with the pharynx. The roof is formed by the hard and soft palate, and the greater part of the floor is formed by the tongue. The space bounded externally by the lips and cheeks and internally by the gums and teeth is called the *vestibule.* The cavity behind this is the *mouth cavity proper.*

The lips are two musculomembranous folds which surround the orifice of the mouth.

The palate consists of a hard portion in front, formed by processes of the maxillæ and palatine bones, which are covered by periosteum and mucous membrane. Suspended from the posterior border is the soft palate, a movable fold of mucous membrane, enclosing muscle fibers, blood-vessels, nerves, adenoid tissue, and mucous

glands. Hanging from the middle of its lower border is a conical process called the palatine *uvula* (little grape).

Fauces. — The fauces is the name given to the aperture leading from the mouth into the pharynx, or throat cavity. From the base of the uvula on either side there passes a curved fold of muscular tissue covered by mucous membrane, which shortly after leaving the uvula is split into two pillars, the one runs downward, lateral-ward, and forward to the side of the base of the tongue, the other downward, lateral-ward and backward to the side of the pharynx. These arches are known respectively as the *glossopalatine arch* (anterior pillars of fauces) and the *pharyngopalatine arch* (posterior pillars of the fauces).

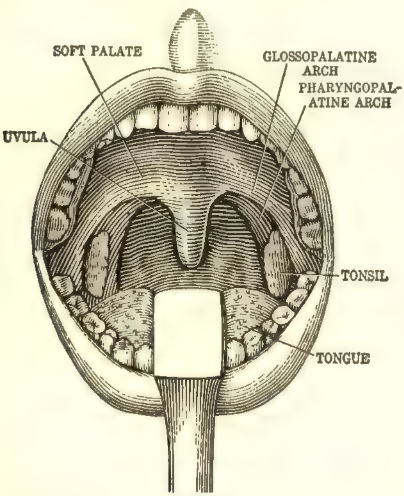


FIG. 209. — THE SOFT PALATE, UVULA, AND TONSILS AS SEEN FROM THE FRONT. (Gerrish.)

The palatine tonsils[1] are two masses of lymphoid tissue situated, one on either side, in the triangular space between the glossopalatine and the pharyngopalatine arches. The surface of the tonsils is marked by openings called crypts, which communicate with channels that course through the substance of the tissue. They are supplied with blood from the lingual and internal maxillary arteries, which are derived from the external carotid arteries. They receive nerve fibers from both divisions of the autonomic system. Situated below the tongue are masses of lymphoid tissue called the *lingual tonsils.*

The function of the tonsils is thought to be similar to that of the lymph-nodes. They aid in the formation of white blood cells and help to protect the body from infection, by acting as filters and preventing the entrance of microörganisms. If they are abnormal, their protective function is reduced, and they may serve as foci of infection which passes directly into the lymph and so into the blood. If they are much enlarged, they tend to fill the throat cavity and interfere with the passage of air to the lungs. Inflammation of the palatine tonsils is called tonsillitis.

[1] As commonly used, the name *tonsil* refers to the palatine tonsils

The palate, uvula, palatine arches, and tonsils are plainly seen if the mouth is widely opened and the tongue depressed.

The tongue. — The tongue is the special organ of the sense of taste. It assists in mastication, deglutition, and digestion, because the movements of the tongue help to move the food and keep it between the teeth, the glands of the tongue secrete mucin, which lubricates the food and makes swallowing easier, and stimulation of the end-organs (taste buds) of the nerves of the sense of taste increases the secretion of saliva and starts the first flow of gastric fluid.

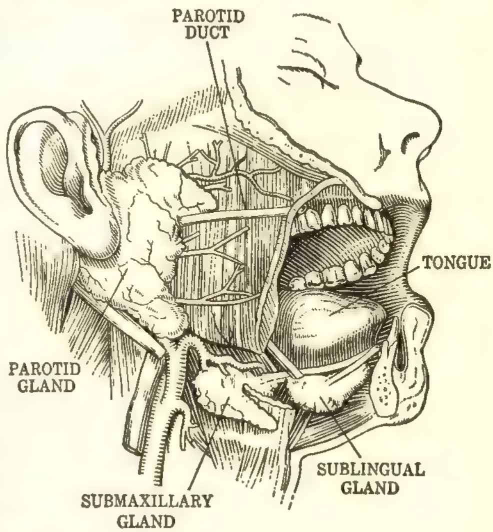


FIG. 210. — THE SALIVARY GLANDS AND THEIR DUCTS.

The salivary glands. — The mucous membrane lining the mouth contains many minute glands, called buccal glands. These pour their secretion into the mouth, but the chief secretion is supplied by the salivary glands, which are three pairs of compound saccular glands called the parotid, submaxillary, and sublingual, respectively. Each *parotid* gland is placed just under and in front of the ear; its duct, the parotid (Stenson's),[2] passes forward and opens upon the inner surface of the cheek opposite the second molar of the upper jaw. The *submaxillary* and *sublingual* glands are situated below the jaw and under the tongue, the submaxillary being placed farther back than the sublingual. One duct (Wharton's) from each submaxillary and a number of small ducts from each sublingual open in the floor of the mouth beneath the tongue. The secretion of the salivary glands, mixed with that of the small glands of the mouth, the buccal secretion, is called *saliva*.

Nerves and blood-vessels. — The facial and glossopharyngeal nerves supply these glands. The fibers are both secretory and vasomotor and are derived from the craniosacral and thoracolumbar

[2] Nicholas Stenson, Danish anatomist, 1638–1686.

systems. Blood is supplied to the salivary glands by branches of the external carotid artery.

The teeth (dentes). — The alveolar processes of the maxillæ and mandible contain sockets or *alveoli* for the reception of the teeth. A dense, insensitive, fibrous membrane covered by smooth mucous membrane–the gums–covers these processes and extends a little way into each socket (alveolus). The sockets are lined by periosteum, which connects with the gums and serves (1) to attach the teeth to their sockets and (2) as a source of nourishment.

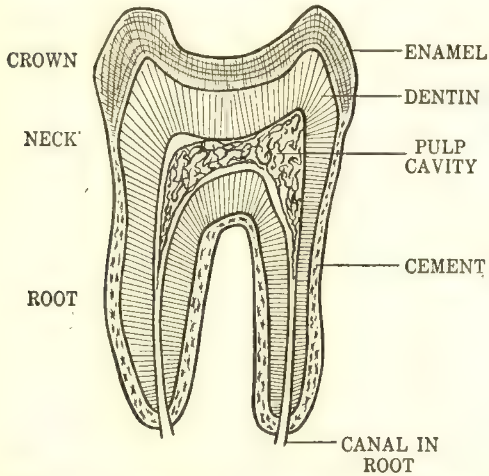


Fig. 211. — Section of Human Molar Tooth.

Each tooth consists of three portions: (1) the *root*, consisting of one or more fangs contained in the socket; (2) the *crown*, which projects beyond the level of the gums; and (3) the *neck* or constricted portion between the root and the crown.

Each tooth is composed principally of ivory or *dentin*, which gives it shape and encloses a cavity, the pulp cavity. The dentin of the crown is capped by a dense layer of *enamel*. The dentin of the root is covered by *cement*. These three substances, enamel, dentin, and cement, are all harder than bone, enamel being the hardest substance found in the body. They are developed from epithelial tissue. The pulp cavity is just under the crown and is continuous with a canal that traverses the center of each root, and opens by a small aperture at its extremity. It is filled with dental pulp, which consists of loose connective tissue holding a number of blood-vessels and nerves which enter by means of the canal from the root.

There are two sets of teeth developed during life: the first, deciduous or milk teeth; and the second, permanent.

Deciduous teeth. — In the first set are twenty teeth, ten in each jaw: four incisors, two canines, and four molars. The cutting of the milk teeth usually begins at six months and ends at about the

age of two years. In nearly all cases the teeth of the lower jaw appear before the corresponding ones of the upper jaw.

DECIDUOUS TEETH

	MOLARS	CANINE	INCISORS	CANINE	MOLARS
Upper......	2	1	4	1	2
Lower......	2	1	4	1	2

The deciduous teeth are usually cut in the following order:

Lower central incisors........................	6 to 9 months
Upper incisors.............................	8 to 10 months
Lower lateral incisors and first molars..........	15 to 21 months
Canines....................................	16 to 20 months
Second molars.............................	20 to 24 months

Permanent teeth. — During childhood the temporary teeth are replaced by the permanent. In the second set are thirty-two permanent teeth, sixteen in each jaw. The first molar usually appears between five and seven years of age.

PERMANENT TEETH

	MOLAR	PREMOLAR	CANINE	INCISOR	CANINE	PREMOLAR	MOLAR
Upper....	3	2	1	4	1	2	3
Lower....	3	2	1	4	1	2	3

The permanent teeth appear at about the following periods:

First molars...............................	6 years
Two central incisors........................	7th year
Two lateral incisors........................	8th year
First premolars.............................	9th year
Second premolars...........................	10th year
Canine.....................................	11th to 12th year
Second molars..............................	12th to 13th year
Third molars...............................	17th to 25th year

There are considerable individual variations in the time of eruption of both the deciduous and permanent teeth. According to their shape and use the teeth are divided into incisors, canine, premolars or bicuspids, and molars.

Incisors are eight in number and form the four front teeth of each jaw. They have a sharp cutting edge, and are specially adapted for biting the food.

Canines are four in number, two in each jaw. The upper canines are commonly called eye teeth; the lower, stomach teeth. They have sharp, pointed edges and are longer than the incisors. In the human being they serve the same purpose as the incisors.

Premolars or bicuspids are eight in number in the permanent set. There are none in the temporary set. There are four in each jaw, two being placed just behind each of the canine teeth. They are broad, with two points or cusps on each crown. These teeth

have only one root; the root, however, is more or less completely divided into two. Their function is to cut and grind food.

Molars are twelve in number in the permanent set, and only eight in the deciduous set. They have broad crowns with small, pointed projections, which make them well fitted for crushing and bruising the food. Each upper molar has three roots, and each lower molar has two roots, which are grooved and indicate a tendency to division. The twelve molars do not replace the temporary teeth, but are gradually added with the growth of the jaws; the last or hindmost molars may not appear until twenty-five years of age; hence called *late teeth* or "wisdom teeth."

Long before the teeth appear through the gums their formation and growth are in progress. The deciduous set begins to develop about the sixth week of intrauterine life; and the permanent set, with the exception of the second and third molars, begins to develop about the sixteenth week. About the third month after birth, the second molars begin to grow, and about the third year the third molars or wisdom teeth do likewise. Diseases such as rickets and marasmus retard the eruption of the temporary teeth, and severe illness during childhood may interfere with the normal development of the permanent teeth so that they are marked with notches and ridges. Moreover, cavities form in them readily. The diet of the mother during pregnancy and the diet of the child during the first years of life are important factors in determining the quality of the teeth and the development of caries. When the central incisors are notched along their cutting edges and the lateral incisors are pegged, they are named Hutchinson's[3] teeth, and are a diagnostic sign of congenital syphilis.

Function. — The teeth assist in the process of mastication by cutting and grinding the food. It might be thought that the vigorous employment of the teeth for this purpose would only hasten their wear and tear. This may be true at a time when their life is nearly extinct, but at an earlier period mastication of the more solid foods is good for the teeth because they are made to sink and rise in their sockets with a massaging effect upon the gums, which tends to promote circulation in the pulp. Proper cleansing of the mouth and teeth tends to prevent the formation of cavities. If particles of food are allowed to remain in the mouth, there is always the danger of the bacteria in the mouth acting upon the teeth and producing acid fermentation, in which case the acid erodes the enamel and dentin.

The pharynx. — The pharynx, or throat cavity, is a musculomembranous tube shaped somewhat like a cone, with its broad end turned upward and its constricted end downward to end in the esophagus. It may be divided from above downward into three parts, nasal, oral, and laryngeal. The upper or *naso-pharynx* lies

[3] Sir Jonathan Hutchinson, English surgeon, 1828–1913.

behind the posterior nares and above the soft palate. The middle or *oral* part of the pharynx reaches from the soft palate to the level of the hyoid bone. The *laryngeal* part reaches from the hyoid bone to the esophagus. The pharynx communicates with the nose, ears, mouth, and larynx by seven apertures.

Two in front above, leading into the back of the nose, the **posterior nares.**

Two on the lateral walls of the naso-pharynx, leading into the auditory tubes, which communicate with the ears.

One midway in front, the **fauces,** connecting with the mouth in front.

Two below, one, the glottis, opening into the larynx and the other into the esophagus.

The mucous membrane lining the pharynx is continuous with that lining the nasal cavities, the mouth, and the larynx. It is well supplied with mucous glands. About the center of the posterior wall of the naso-pharynx is a mass of lymphoid tissue, — the pharyngeal tonsil, — commonly called *adenoids.*

Usually lymphoid tissue is larger in children than in adults and tends to grow smaller with age. Owing to their position, adenoids may become infected or enlarged, block the auditory tubes and interfere with the passage of air through the nose. Under such conditions, surgical removal is recommended.

Nerves and blood-vessels. — Both divisions of the autonomic system supply nerve fibers to the pharynx. These are both sensory and motor fibers within the glossopharyngeal and vagus nerves. Blood is supplied by branches from the external carotid artery.

Function. — The pharynx (1) transmits the air from the mouth or nose to the larynx, and (2) serves as a resonating cavity in the production of the voice. (3) When the act of swallowing is about to be performed, the muscles draw the pharynx upward and dilate it to receive the food; they then relax, the pharynx sinks, and the other muscles contracting upon the food, it is pressed downward and onward into the esophagus.

The esophagus, or gullet. — The esophagus is a muscular tube, about 22.5 cm. to 25 cm. (9–10 in.) long, which begins at the lower end of the pharynx, behind the trachea. It descends in front of the vertebral column, passes through the diaphragm, and terminates in the upper or cardiac end of the stomach.

Structure. — The walls of the esophagus are composed of four coats: (1) an external or fibrous, (2) a muscular, (3) a submucous or areolar, and (4) an internal or mucous coat. The muscular coat is arranged in an external longitudinal and an internal circular

layer. Contraction of these layers produces a peristaltic wave, which propels the bolus of food to the stomach. The areolar coat serves to connect the muscular and mucous coats. The mucous membrane is disposed in longitudinal folds which disappear when the tube is distended by the passage of food. It is studded with minute papillæ and small glands, which secrete mucus to lubricate the canal.

Nerves and blood-vessels. — The nerve fibers are from the vagus and the thoracolumbar system. They form a plexus between the layers of the muscular coat and another in the submucous coat. Blood is supplied to the esophagus by arteries (1) from the inferior thyroid branch of the thyrocervical trunk, which arises from the subclavian, (2) from the thoracic aorta, (3) from the left gastric branch of the celiac artery, and (4) from the left inferior phrenic of the abdominal aorta.

Function. — The esophagus serves (1) to connect the pharynx with the stomach, and (2) to receive the food from the pharynx and by a series of peristaltic contractions pass it on to the stomach.

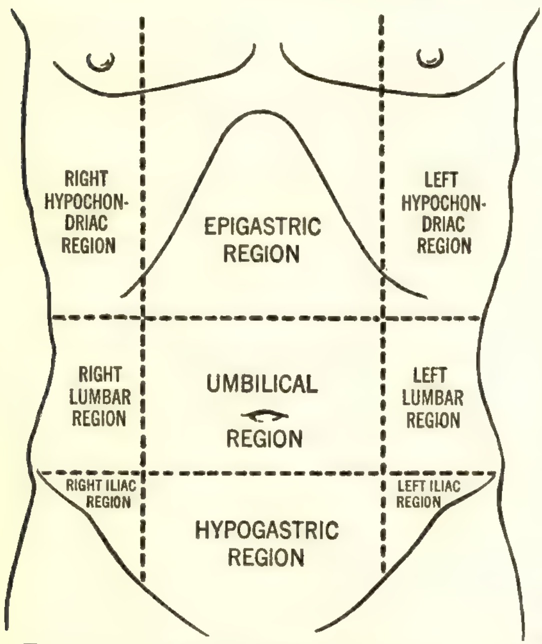


FIG. 212. — THE NINE REGIONS OF THE ABDOMEN. For convenience of description, the abdomen may be artificially divided into nine regions by drawing the following arbitrary lines:

1. Draw a circular line around the body at the level of the lowest point of the tenth costal cartilages. 2. Draw another circular line at the level of the tubercles on the crests of the ilia. 3. Draw a vertical line on each side from the center of Poupart's ligament upward. These lines are to be considered as edges of planes which divide the abdomen into the nine regions. (Cunningham.)

THE STOMACH

After reaching the abdominal cavity, the esophagus ends in the stomach (gaster), which is a collapsible sac-like dilatation of the alimentary canal and serves as a temporary receptacle for food. It lies ob-

liquely in the epigastric, umbilical, and left hypochondriac regions of the abdomen, directly under the diaphragm. The shape and position of the stomach are modified by changes within itself, and in the surrounding organs. These modifications are determined by (1) the amount of the stomach contents, (2) the stage of digestion which has been reached, (3) the degree of development and power of the muscular walls, and (4) the condition of the adjacent intestines. It is never entirely empty but always contains a few cubic centimeters of gastric fluid and mucin. When contracted,

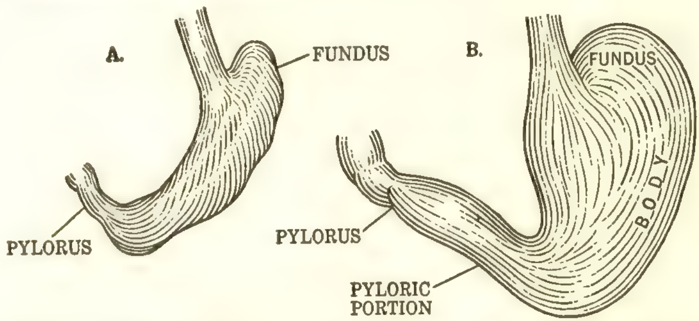


FIG. 213. — FORM AND OUTLINE OF THE STOMACH AT DIFFERENT STAGES OF DIGESTION. *A*, when contracted. *B*, at an early stage of gastric digestion.

the shape of the stomach is comparable to a sickle or sausage. At an early stage of gastric digestion, the stomach usually consists of two segments, a large globular portion on the left, and a narrow tubular portion on the right. When distended with food, it has the shape shown in Fig. 213. The stomach presents two openings and two borders or curvatures.

Openings. — The opening by which the esophagus communicates with the stomach is known as the cardiac or esophageal orifice, and the orifice which communicates with the duodenum is known as the pyloric. Both the cardiac and pyloric apertures are guarded by ring-like muscles known as sphincters which when contracted keep the orifices closed. They are contracted except when food is passing through them. By this arrangement, the food is kept in the stomach until it is ready for intestinal digestion, when the circular fibers guarding the pyloric aperture relax. The relaxation of this aperture seems to be connected with the consistency and acidity of the stomach contents. Solid objects forced against the pylorus prevent relaxation, but liquid food passes from the stomach into the duodenum in a few minutes. Hydrochloric acid in the stomach seems to favor or produce a relaxation of the pyloric sphincter.

Curvatures. — In all positions the stomach is more or less curved upon itself. A line drawn from the cardiac orifice along the concave border to the pyloric orifice is said to follow the lesser curvature. A much longer line connecting the same points, but following the convex border, defines the greater curvature.

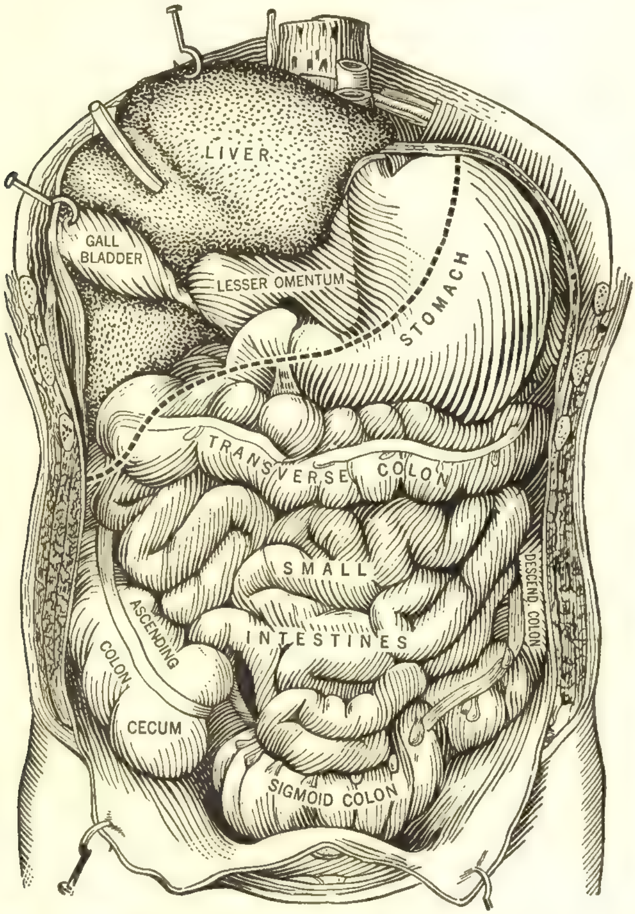


Fig. 214. — The Stomach and Intestines, Front View, the Great Omentum Having Been Removed, and the Liver Turned Up and to the Right. The dotted line shows the normal position of the anterior border of the liver. (Gerrish.)

Component parts. — The *fundus* is the blind, rounded end of the stomach, above the entrance of the esophagus. The opposite or smaller end is called the *pyloric portion.* The central portion, between the fundus and the pyloric portion, is called the *body.*

Structure. — The wall of the stomach consists of four coats: (1) serous, (2) muscular, (3) submucous or areolar, and (4) mucous.

(1) The **serous** coat is part of the peritoneum, and covers both surfaces of the organ. At the lesser curvature, the two layers come together and are continued upward to the liver as the *lesser omentum.* At the greater curvature, the two layers are continued downward and form an apron-like appendage, the *greater omentum,* which is suspended in front of the intestines.

(2) The **muscular** coat of the stomach is beneath the serous coat and closely connected with it. It consists of three layers of unstriped muscular tissue: an outer, longitudinal layer; a middle or circular layer; and an inner, less well-developed, oblique layer limited chiefly to the cardiac end of the stomach. This arrangement facilitates the peristaltic action of the stomach by which it presses upon the food and moves it back and forth.

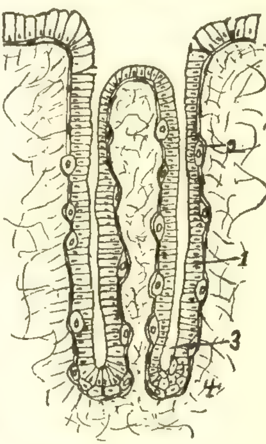


FIG. 215. — GASTRIC GLANDS SHOWING AT 1, chief or central cells; 2, the parietal or oxyntic cells; 3, lumen, and 4, connective tissue surrounding gland.

(3) The **submucous** coat consists of loose areolar connective tissue connecting the muscular and mucous coats.

(4) The **mucous** coat is very soft and thick, the thickness being mainly due to the fact that it is densely packed with small glands embedded in areolar connective tissue. It is covered with columnar epithelium, and in its undistended condition is thrown into folds or rugæ. The surface is honeycombed by tiny, shallow pits, into which the ducts or mouths of the glands open.

Gastric glands. — The gastric glands are of three varieties, (1) cardiac; (2) fundic or oxyntic;[4] and (3) pyloric.

(1) Cardiac glands occur close to the cardiac orifice. They are of two kinds, simple tubular glands with short ducts, and compound racemose glands. (2) Fundic glands are simple tubular glands which are found in the body and fundus of the stomach. These glands are lined by epithelial cells, of which there are two varieties. (*a*) One variety of cell is found lining the lumen of the tube. These are called chief or central cells and secrete pepsinogen. (*b*) A second variety called parietal or oxyntic cells are found behind the chief cells, where they do not come in contact with the

[4] Also called true gastric or peptic.

lumen. These cells secrete hydrochloric acid, and pepsinogen in the presence of acid is converted into pepsin.

(3) Pyloric glands are branched tubular glands found most plentifully about the pylorus. They secrete pepsinogen and mucin.

The combined secretion of these glands forms the gastric fluid.

Some of the cells of the mucous membrane secrete a hormone known as gastrin, which is carried by the blood to the fundic and pyloric glands, and stimulates them to secretory activity.

Nerves and blood-vessels. — The stomach is supplied with thoracolumbar autonomic nerve fibers from the celiac plexus. Terminal branches of the right vagus are distributed to the back of the organ, and terminal branches from the left vagus are distributed to the front. Stimulation of the vagus fibers increases secretion and peristalsis. Stimulation of the thoracolumbar autonomic fibers has just the opposite effect, *i.e.*, inhibits secretion and peristalsis. The blood-vessels are derived from the three divisions of the celiac, *i.e.*, the left gastric, and branches of the hepatic and splenic or lienal.

Functions. — Functions of the stomach are to connect the esophagus with the intestine. To receive the food in relatively large quantities, say about three times a day, and hold it while it undergoes certain mechanical and chemical changes, which reduce it to a semi-liquid condition (chyme). At frequent intervals small amounts of this chyme are passed to the intestine. To secrete gastric fluid.

THE SMALL, OR THIN INTESTINE

The small intestine extends from the pylorus to the colic valve. It is a convoluted tube about 7 m. (23 ft.)[5] in length, and is contained in the central and lower part of the abdominal cavity.

At the beginning the diameter is about 3.8 cm. (1½ in.), but it gradually diminishes in size and is hardly an inch in diameter at its lower end. For descriptive purposes the small intestine is divided into three portions: the duodenum, jejunum, and ileum, but they are all continuous and show only slight variations.

The duodenum. — The duodenum is twelve fingers' breadth in length (25 cm. or ten inches), and is the shortest and broadest part of the small intestine. It extends from the pyloric end of the stomach to the jejunum.

Beginning at the pylorus, the duodenum at first passes upward, backward, and to the right, beneath the liver. It then makes a

[5] The length of the small intestine and of its various parts is variable.

sharp bend and passes downward in front of the right kidney; it now makes a second bend, toward the left, and passes horizontally across the front of the vertebral column. On the left side, it ascends for about 2.5 cm. (1 in.), and then ends opposite the second lumbar vertebra in the jejunum.

The jejunum. — The jejunum, or empty intestine, so called because it is always found empty after death, constitutes about two-fifths of the remainder, or 2.2 m. ($7\frac{1}{2}$ ft.), of the small intestine, and extends from the duodenum to the ileum.

The ileum. — The ileum, or twisted intestine, so called from its numerous coils, constitutes the remainder of the small intestine, and extends from the jejunum to the large intestine, which it joins at a right angle. The orifice is guarded by a sphincter muscle which acts as a valve, and prevents the return of material that has been discharged into the large bowel. This is known as the colic or ileocecal valve.

There is no definite landmark to determine the point at which the jejunum ceases and the ileum begins, although the mucous membrane of the one differs somewhat from the mucous membrane of the other; the change is a gradual transition, and one structure shades off into the other.

Coats of the small intestine. — The small intestine has four coats, which correspond in character and arrangement with those of the stomach. (1) The **serous** coat furnished by the peritoneum forms an almost complete covering for the whole tube except for part of the duodenum. (2) The **muscular** coat of the small intestine has only two layers: an outer, thinner, and longitudinal; and an inner, thicker, and circular. This arrangement aids the peristaltic action of the intestine. (3) The **submucous,** or areolar connective tissue coat, connects the muscular and mucous coats. (4) The **mucous** coat is thick and very vascular.

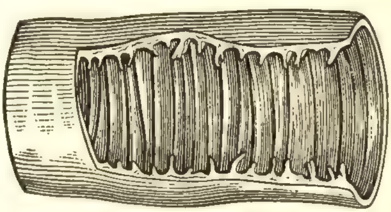


FIG. 216. — PORTION OF SMALL INTESTINE LAID OPEN TO SHOW CIRCULAR FOLDS (valvulæ conniventes). Not highly enough magnified to show villi.

Circular folds. — About 3 or 4 cm. (1 or 2 in.) beyond the pylorus the mucous and submucous coats of the small intestine are arranged in circular folds (valvulæ conniventes or plicæ circulares) which project into the lumen of the tube. Some of these folds extend all the way around the circumference of the intestine;

others extend only one-half or one-third of the way. Unlike the rugæ of the stomach, the circular folds do not disappear when the intestine is distended. About the middle of the jejunum they begin to decrease in size, and in the lower part of the ileum they almost entirely disappear. The purpose of these folds is: (1) to prevent the food from passing through the intestines too quickly, and (2) to present a greater surface for the absorption of digested food.

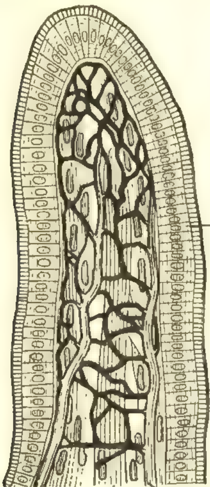


FIG. 217. — AN INTESTINAL VILLUS. (Highly magnified.)

Villi. — Throughout the whole length of the small intestine the mucous membrane presents a velvety appearance due to minute finger-like projections called *villi* which are said to number between four and five million in man. Each villus consists of a central lymph-channel called a lacteal, surrounded by a network of blood capillaries, held together by lymphoid tissue. This in turn is surrounded by a layer of columnar cells. After the food has been digested it passes into the capillaries and lacteals of the villi.

Glands and nodes of the small intestine. — In addition to these projections the mucous membrane is thickly studded with secretory glands and nodes. These are known as —

1. Intestinal glands or crypts of Lieberkuhn.[6]
2. Duodenal or Brunner's glands.
3. Lymph-nodules { (*a*) Solitary lymph-nodules. (*b*) Aggregated lymph-nodules.

Intestinal glands. — These glands are found over every part of the surface of the small intestine. They are simply tubular depressions in the mucous membrane, lined with columnar epithelium and opening upon the surface by circular apertures.

Duodenal glands. — These are compound glands found in the submucous tissue of the duodenum. The intestinal glands and the

[6] Johann Nathaniel Lieberkuhn, German anatomist, 1711–1756. Johann Conrad Brunner, Swiss anatomist, 1653–1727.

duodenal glands secrete the intestinal digestive fluid which is named the succus entericus.

Lymph-nodules. — (*a*) Closely connected with the lymphatic vessels in the walls of the intestines are small, rounded bodies of the size of a small pin's head, called *solitary lymph-nodules.* They are most numerous in the lower part of the ileum and consist of a rounded mass of fine lymphoid tissue, the meshes of which are crowded with leucocytes. Into this mass of tissue one or more small arteries enter and form a capillary network, from which the blood is carried away by one or more small veins. Surrounding the mass are lymph channels which are continuous with the lymphatic vessels in the tissue below.

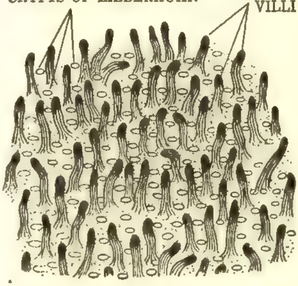


FIG. 218. — MUCOUS MEMBRANE OF THE ILEUM, SHOWING VILLI AND THE MOUTHS OF THE INTESTINAL GLANDS.

(*b*) *Aggregated lymph-nodules* are collections of lymph-nodules, commonly called Peyer's [7] patches. These patches are circular or oval in shape, from ten to thirty in number, and vary in length from about 2.5 to 10 cm. (1 in.–4 in.). They are largest and most numerous in the ileum. In the lower part of the jejunum they are small and few in number. They are occasionally seen in the duodenum. Peyer's patches may be the seat of local inflammation and ulceration in typhoid fever and intestinal infections, particularly tuberculosis of the intestines.

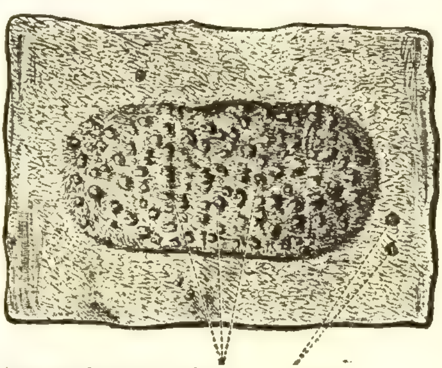


FIG. 219. — AGGREGATED LYMPH-NODULE. (Peyer's patch.)

Nerves and blood-vessels. — The vagus nerves supply sensory and motor fibers to the small intestine. Thoracolumbar nerve fibers are derived from the plexuses around the superior mesenteric artery. From this source they run to the myenteric plexus (Auerbach's plexus) of nerves and ganglia situated between the circular and

[7] Johann Konrad Peyer, Swiss anatomist, 1653–1712.

longitudinal muscular fibers. Branches from this plexus are distributed to the muscular coats, and from these branches a secondary plexus, the submucous (Meissner's) plexus, is derived. It sends fibers to the mucous membrane. The arteries supplying the small intestine are branches of the superior mesenteric. These vessels distribute arched branches, which lie between the serous and muscular coats and form frequent anastomoses. Blood is returned by the superior mesenteric vein, which unites with the splenic to form the portal tube.

Functions. — It is in the small intestine that the greatest amount of digestion and absorption takes place. It receives the bile from the liver and the pancreatic fluid from the pancreas. The glands of the small intestine secrete the succus entericus. The circular folds delay the food so that it is more thoroughly subjected to the action of these digestive fluids; and being covered with villi they increase the surface for absorption. Some of the cells of the mucous membrane (particularly in the duodenum) secrete a substance known as prosecretin. When the acid chyme enters the intestine, prosecretin is changed to secretin and carried by the blood to the liver, pancreas, and all parts of the intestine, stimulating them to secretory activity.

THE LARGE, OR THICK INTESTINE

The large intestine is only about 1.5 m. (5 ft.) long, but is wider than the small intestine, being about 6.3 cm. ($2\frac{1}{2}$ in.) at the cecum. It extends from the ileum to the anus. It is divided into four parts: the cecum with the vermiform appendix, colon, rectum, and anal canal.

The cecum. — The cecum is a large blind pouch at the commencement of the large intestine. The small intestine opens into the side wall of the large intestine about 6 cm. ($2\frac{1}{2}$ in.) above the commencement of the large intestine. This 6 cm. of large intestine forms a cul-de-sac called the cecum. The opening from the ileum into the large intestine is provided with two large projecting lips of mucous membrane which allow the passage of material into the large intestine, but effectually prevent the passage of material in the opposite direction. These mucous folds form what is known as the colic or ileocecal valve.

The vermiform appendix is a narrow, worm-like tube attached to the end of the cecum. The length, diameter, direction, and relations of the appendix are very variable. The average length is about 7.5 cm. (3 in.)

The function of the appendix is not known. It is most fully developed in the young adult, and at this time is subject to inflammatory and gangrenous conditions commonly called appendicitis. The reasons for this are: its structure does not allow of ready drainage, its blood-supply is limited, and its circulation is easily checked, because the vessels anastomose to a very limited extent.

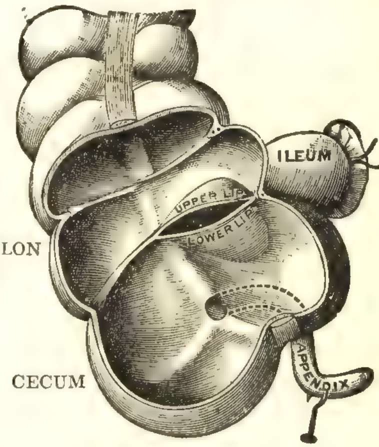


FIG. 220. — CAVITY OF THE CECUM, ITS FRONT WALL HAVING BEEN CUT AWAY. The valve of the colon (colic) and the opening of the appendix are shown. (Gerrish.)

The colon. — The colon, though one continuous tube, is subdivided into the *ascending*, *transverse* or *mesial*, *descending*, and the *sigmoid colon*. The ascending portion ascends on the right side of the abdomen until it reaches the under surface of the liver, where it bends abruptly to the left (right colic or hepatic flexure), and is continued across the abdomen as the transverse colon until, reaching the left side, it curves beneath the lower end of the spleen (left colic or splenic flexure), and passes downward as the descending colon. Reaching the left iliac region on a level with the margin of the crest of the ileum, it makes a curve like the letter S, — hence its name of sigmoid, — and finally ends in the rectum. (See Fig. 214.)

The rectum. — The rectum is about 12 cm. (5 in.) long; from its origin at the third sacral vertebra it descends along the curve of the sacrum and the coccyx, and finally bends sharply backward into the anal canal.

The anal canal. — The anal canal is the terminal portion of the large intestine, and is about 2.5 to 3.8 cm. (1–1½ in.) in length. The external aperture called the *anus* is guarded by an internal[8] and external sphincter. It is kept closed except during defecation.

Coats of the large intestine. — The large intestine has the usual four coats, except in some parts where the serous coat only partially covers it, and in the anal canal, where the serous coat is lacking. The **muscular** coat consists of two layers of fibers, the external arranged longitudinally and the internal circularly. The

[8] It is really a thickening of the circular fibers of the muscular coat.

longitudinal fibers do not form a continuous layer over the whole surface of the large intestine. Instead they are arranged in three separate bands, which extend from the cecum to the beginning of the rectum, where they spread out and form a circular layer which encircles this portion. These bands being shorter than the rest of the tube, the walls are puckered into numerous sacculations. The third coat consists of **submucous areolar tissue,** and the fourth or inner coat consists of **mucous membrane.** The mucous coat possesses no villi and no circular folds. It contains intestinal glands and solitary lymph-nodules which closely resemble those of the small intestine.

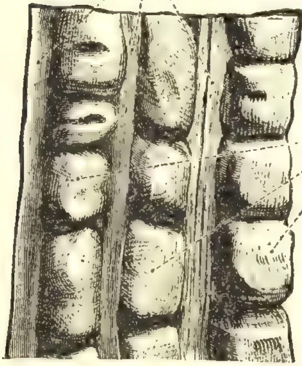


FIG. 221.—THE MUSCULAR COAT OF THE OPENED LARGE INTESTINE, SHOWING THE LONGITUDINAL FIBERS.

Nerves and blood-vessels. — Fibers from both divisions of the autonomic system reach the large intestine, nerves from the mesenteric and hypogastric plexuses being distributed in a similar way to that found in the small intestine. The arteries are derived mainly from the superior and inferior mesenteric arteries. Branches of the superior mesenteric artery supply the cecum, appendix, ascending and transverse colon. Branches of the inferior mesenteric artery supply the descending colon and rectum. The rectum also receives branches from the hypogastric arteries.

Functions. — The process of digestion is continued due to the digestive fluids with which the food becomes mixed in the small intestine, the process of absorption is continued, and the waste products are removed from the body.

ACCESSORY ORGANS OF DIGESTION

The accessory organs of digestion are: (1) the tongue, (2) the teeth, (3) the salivary glands, (4) the pancreas, and (5) the liver. The first three have been described.

Pancreas. — The pancreas lies in front of the first and second lumbar vertebræ and behind the stomach. In shape it somewhat resembles a hammer, and is divided into head, body, and tail. The right end, or head, is thicker and fills the curve of the duodenum, to which it is firmly attached. The left, free end, is the tail, and reaches to the spleen. The intervening portion is the body. Its average weight is between 60 to 90 grams (2 to 3 oz.), it is about 12.5 cm. (5 in.) long, and about 5 cm. (2 in.) wide.

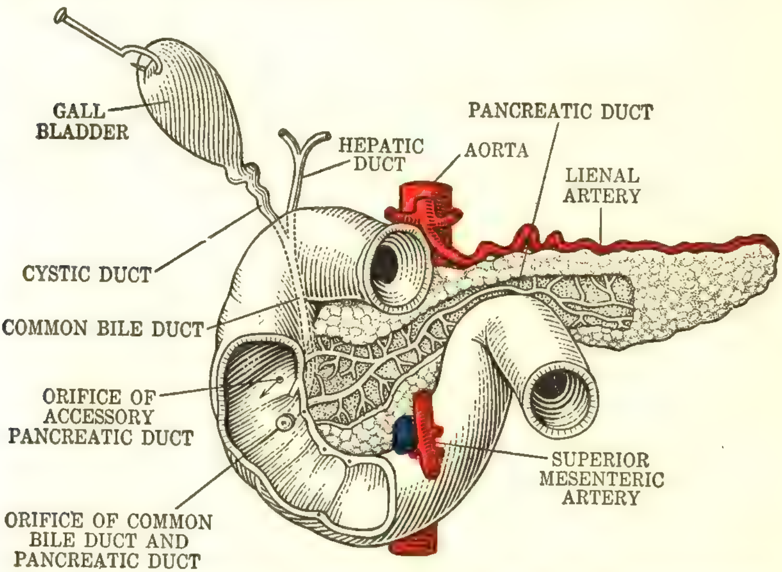


FIG. 222. — DUCTS OF THE PANCREAS. Part of the front of the duodenum is cut away. (Gerrish.)

Structure of the pancreas. — It is a racemose gland composed of lobules. Each lobule consists of one of the branches of the main duct which terminates in a cluster of pouches or alveoli. The lobules are joined together by areolar tissue to form lobes, and the lobes, united in the same manner, form the gland. The small ducts from each lobule open into one main duct about the size of a goose-quill, which runs transversely from the tail to the head through the substance of the gland. This is known as the pancreatic duct or duct of Wirsung.[9] The pancreatic and common bile duct usually unite, and enter the duodenum about 7.5 cm. (3 in.) below the pylorus. The short tube formed by the union of the two ducts is dilated into an ampulla, called the *ampulla of Vater*.[10]

[9] Johann Georg Wirsung, Bavarian anatomist, born 1643.
[10] Abraham Vater, German anatomist, 1684–1751.

Sometimes the pancreatic duct and the common bile duct open separately into the duodenum, and there is frequently an accessory duct (duct of Santorini)[11] which opens into the duodenum about an inch above the orifice of the main duct.

Islands of Langerhans. — Between the alveoli small groups of cells are found, which are termed the islands of Langerhans[12] (interalveolar cell islets). They are surrounded by a rich capillary network. Their function is to furnish the internal secretion of the pancreas.

Function. — Two secretions are formed in the pancreas. (1) The pancreatic fluid, one of the most important of the digestive fluids, is an external secretion and is poured into the duodenum during intestinal digestion. (2) The secretion formed by the islands of Langerhans is an internal secretion from which insulin has been extracted. It is absorbed by the blood and carried to the tissues. This internal secretion aids in regulating glucose metabolism.

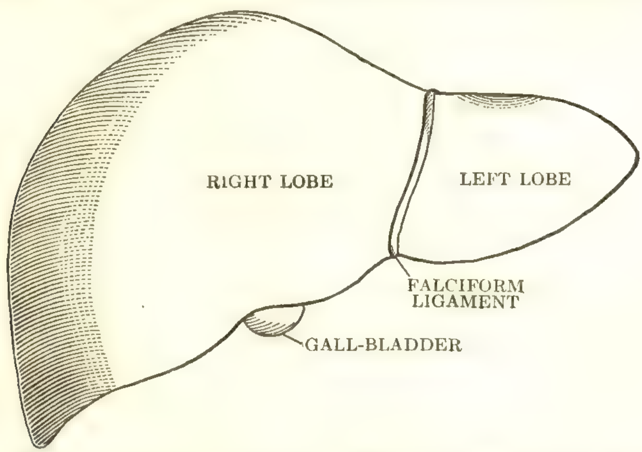


FIG. 223. — THE LIVER. Front view. The liver measures 20 to 22.5 cm. (eight to nine inches) from side to side, 10 to 12.5 cm. (four to five inches) from front to back, and 15 to 17.5 cm. (six to seven inches) from above downward in its thickest part. (Gerrish.)

THE LIVER

The liver (hepar) is the largest gland in the body, weighing ordinarily from 1.2–1.6 kilograms (42 to 56 ounces). It is located in the right hypochondriac and epigastric regions and frequently extends into the left hypochondriac region. The upper convex surface fits closely into the under surface of the diaphragm. The

[11] Giovanni Domenico Santorini, Italian anatomist, 1681–1737.
[12] Paul Langerhans, German anatomist, 1847–1888.

under concave surface of the organ fits over the right kidney, the upper portion of the ascending colon, and the pyloric end of the stomach.

Ligaments. — The liver is connected to the under surface of the diaphragm, and the anterior walls of the abdomen by five ligaments, four of which — the falciform, the coronary, and the two

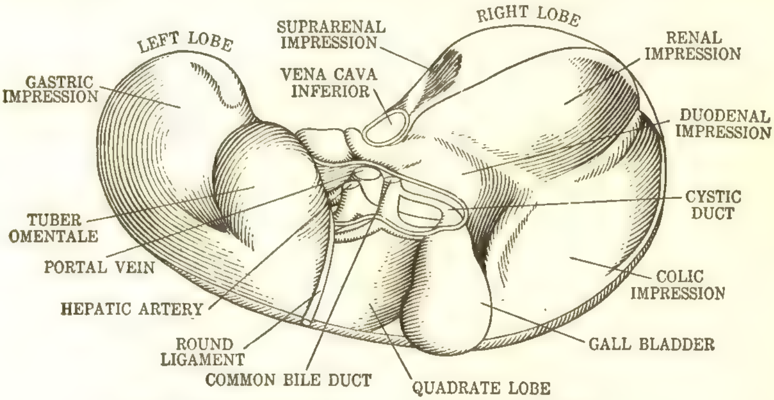


FIG. 224. — THE LIVER. Lower surface. (Gerrish.)

lateral — are formed by folds of peritoneum. The fifth, or round ligament, is a fibrous cord resulting from the atrophy of the umbilical vein of intrauterine life.

Fossæ. — The liver is divided by four fossæ[13] into four lobes. The important fossæ are (1) the left sagittal; (2) the portal, or transverse, which transmits the portal tube, hepatic artery, nerves, hepatic duct, and lymphatics; (3) the fossa for the gall-bladder, and (4) the fossa for the inferior vena cava.

Lobes. — The liver is divided into four lobes:

1. Right (largest lobe).
2. Left (smaller and wedge-shaped).
3. Quadrate (square).
4. Caudate (tail-like).

Vessels. — The liver has five sets of vessels:

1. Branches of portal tube.
2. Bile ducts.
3. Branches of hepatic artery.
4. Hepatic veins.
5. Lymphatics.

Nerves and blood-vessels. — The nerve fibers are derived from the left vagus and the thoracolumbar system. They enter at the transverse fossa and accompany the vessels and ducts to the interlobular spaces. From here fibers are distributed to the coats

[13] Also called fissures.

of the blood-vessels and ramify between and within the cells. The blood-vessels connected with the liver are the hepatic artery, the portal tube, and the hepatic veins.

Anatomy of liver. — The liver may be regarded as made up of many minute livers called lobules. Each **lobule** is an irregular body about 1–2.5 mm. ($\frac{1}{20}$ to $\frac{1}{10}$ in.) in diameter, composed of cords of hepatic cells held together by areolar connective tissue in which ramify capillaries derived from the portal tube and the hepatic artery, nerves, lymphatics, and the hepatic ducts. Thus each lobule has all the essentials of a gland; (1) blood-vessels in close connection with secretory cells, (2) cells which are capable of forming a secretion, and (3) ducts by which the secretion is carried away.

The portal tube brings to the liver venous blood from the stomach, spleen, pancreas, and intestines. After entering the liver, it divides into a vast number of branches which form a plexus, the interlobular plexus in the spaces between the lobules. From this plexus the blood is carried into the lobule by fine branches which converge toward the center. The walls of these small vessels are incomplete, so that the blood is brought in direct contact with each cell. These channels are termed *sinusoids*, and at the center of the lobule they empty the blood into the intralobular vein. The intralobular veins from a number of lobules empty into a much larger vein upon whose surface a vast number of lobules rest, and therefore the name **sublobular** (under the lobule) is given to these veins. They empty into still larger veins, the **hepatic,** which converge to form three large trunks and empty into the **inferior vena cava,** which is embedded in the posterior surface of the gland.

The bile-ducts. — The surfaces of the hepatic cells are grooved, and the grooves on two adjacent cells fit together and form a passage into which the bile is poured as soon as it is formed by the cells. These passages form a network between and around the cells as intricate as the network of blood-vessels. They are called *intercellular biliary passages*, and radiate to the circumference of the lobule, where they empty into the interlobular bile-ducts. These unite and form larger and larger ducts until two main ducts, one from the right and one from the left side of the liver, unite in the portal fossa and form the *hepatic duct.*

The **hepatic duct** passes downward and to the right for about 5 cm. (two inches) and then joins (at an acute angle) the duct from the gall-bladder, termed the *cystic duct.* The hepatic and cystic

ducts together form the *common bile-duct* (*ductus choledochus*), which passes downward for about 7.5 cm. (three inches) and enters the duodenum about 7.5 cm. (three inches) below the pylorus. This orifice usually serves as a common opening for both

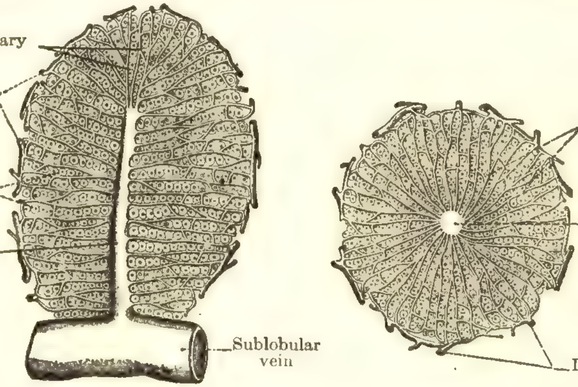


FIG. 225. — *A*, DIAGRAM OF A LONGITUDINALLY DIVIDED HEPATIC LOBULE. *B*, DIAGRAM OF A TRANSVERSELY DIVIDED HEPATIC LOBULE.

the common bile duct and the pancreatic duct. It is very small and is guarded by a sphincter muscle, which keeps it closed except during digestion.

Hepatic artery. — The blood brought to the liver by the portal tube is venous blood and is not intended for purposes of respiration of the liver itself, hence arterial blood is furnished by the *hepatic artery.* It enters the liver with the portal tube, divides and subdivides in the same manner as the portal tubes, thus forming another network between the lobules, and in the lobules between the cells. The capillaries from the portal tube and the hepatic artery are separate and distinct until, near the center of each lobule they empty into the intralobular vein. From here the blood from the hepatic artery and from the portal tube is returned by the hepatic veins which empty into the inferior vena cava.

Lymphatics. — There is a superficial and a deep set of lymphatic vessels. They begin in irregular spaces in the lobules, form networks around the lobules, and run always from the center outward.

The liver is invested in an outer capsule of fibrous tissue called *Glisson's capsule.* This capsule is reflected inward at the transverse fossa and envelops the vessels and ducts which pass into the liver. With the exception of a few small areas, the liver is enclosed in a serous tunic derived from the peritoneum.

Functions. — The liver ~~has important functions~~:

Bile production. — The cells of the liver manufacture bile. The function of bile is considered in the next chapter.

Glycogenic. — The cells of the liver take from the blood brought to them by the portal tube a substance called glucose, which is derived from the carbohydrates of our food. This is stored in the liver in the form of glycogen until such times as the body needs more glucose than the food furnishes. When such demand is made, the enzymes of the liver cells reconvert the glycogen into glucose and pour it into the circulation.

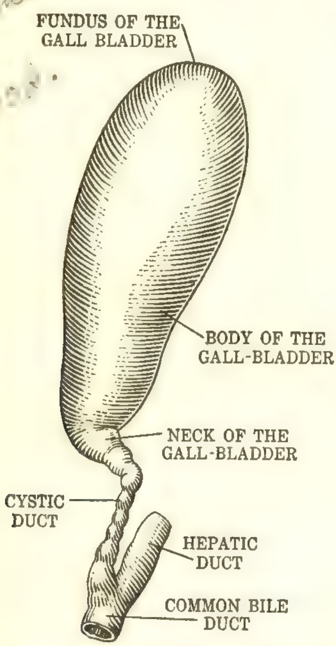


Fig. 226. — The Gall-Bladder, Moderately Distended, with the Cystic Duct and the Junction of the Latter with the Hepatic Duct to Form the Common Bile-Duct.

Secretory. — It is assumed that the liver furnishes an internal secretion which helps to regulate the changing of glucose to glycogen and then to glucose again.

Protective. — Its protective function is exercised in three ways: (*a*) Many of the waste products of protein digestion cannot be eliminated until they are acted upon by the liver, and changed into other substances which the kidneys can eliminate, *e.g.*, urea is made from some of these waste products brought to the liver by the blood. (*b*) It probably finishes the disintegration of the worn-out erythrocytes, which process is commenced in the spleen. (*c*) It plays a part in the clotting of the blood, because it gives rise to heparin.

The gall-bladder. — The gall-bladder is a pear-shaped sac lodged in the gall-bladder fossa on the under surface of the liver, where it is held in place by connective tissue. It is about 7 to 10 cm. (three to four inches) long, 2.5 cm. (one inch) wide, and holds about 36 cc. (nine drachms). It is composed of three coats: (1) the inner one is mucous membrane, (2) the middle one is muscular and fibrous tissue, and (3) the outer one is serous membrane derived from the peritoneum. It is only occasionally that the peritoneum covers more than the under surface of the organ.

Function. — The gall-bladder serves as a reservoir for the bile. In the intervals between digestion, *i.e.*, when the duodenum is empty, the sphincter guarding the bile-duct is contracted and the bile is held in the gall-bladder. It is thought that the acid chyme entering the duodenum relaxes the sphincter, and the gall-bladder contracts and forces out its contents, which pour into the duodenum.

SUMMARY

Digestion. — Digestion is dependent on the proper functioning of certain organs that are grouped together and called the digestive system.

- **Digestive System**
  - **Alimentary canal**
    - Mouth.
    - Pharynx.
    - Esophagus, or gullet.
    - Stomach.
    - Small or thin intestine
      - Duodenum.
      - Jejunum.
      - Ileum.
    - Large or thick intestine
      - Cecum.
      - Colon
        - Ascending.
        - Transverse or mesial.
        - Descending.
        - Sigmoid.
      - Rectum,
      - Anal canal.
  - **Accessory organs**
    - Tongue.
    - Teeth.
    - Salivary glands.
    - Pancreas.
    - Liver.

- **Alimentary Canal**
  - Continuous tube from mouth to anus.
  - About 9 m. (30 ft.) long
  - Esophagus — 4 coats
    - Internal or mucous.
    - Submucous or areolar.
    - Muscular.
    - Fibrous.
  - From diaphragm to rectum — 4 coats
    - Mucous.
    - Submucous or areolar.
    - Muscular.
    - Peritoneum.

- **Mouth, or Buccal Cavity**
  - Roof — palate
    1. Hard palate — Maxillæ, Palatine processes.
    2. Soft palate — uvula, palatine arches, and tonsils.
  - Floor — tongue.
  - Bounded laterally and in front by cheeks and lips.
  - Behind it communicates with pharynx.
  - Contains
    - Tonsils. Orifices of ducts of salivary glands.
    - Tongue. Teeth.

- **Tonsils**
  - Masses of lymphoid tissue occupy triangular space between palatine arches on either side of throat.
  - **Function**
    - Similar to that of lymph-nodes.
    - 1. Aid in formation of white cells.
    - 2. Act as filters and protect body from infection.
- **Tongue**
  - Special organ of sense of taste.
  - Assists in
    - Mastication.
    - Deglutition.
    - Digestion.
- **Salivary Glands**
  - Parotid — just under and in front of ear.
  - Submaxillary, Sublingual — Below the jaw and under the tongue.
  - **Function** — Form a secretion, which mixed with the secretion of the glandular cells of the mouth is called saliva.
  - **Nerves** — Fibers from both divisions of autonomic system.
  - **Blood-vessels** — Branches of the external carotid artery.
- **Teeth**
  - Contained in sockets of alveolar processes of maxillæ and mandible.
  - **Gums** — cover processes and extend into sockets or alveoli.
  - **Sockets** — lined with periosteum
    - Attaches teeth to sockets.
    - Source of nourishment.
  - 3 portions
    - *Root* — one or more fangs contained in alveolus.
    - *Crown* — projects beyond level of gums.
    - *Neck* — portion between root and crown.
  - Composed of three substances developed from epithelium
    - *Ivory or Dentin* — Gives shape. Encloses pulp cavity which contains nerves and blood-vessels, that enter by canal from root.
    - *Enamel* — Caps the crown.
    - *Cement* — Covers the root.
  - 2 sets
    - 1. Deciduous — 6 months to 2 yrs.
      - Incisors 8
      - Canines 4
      - Molars 8
      - 20.
    - Begin to develop about the sixth week of intrauterine life.
    - 2. Permanent— 6½ yrs. to 25 yrs. of age
      - Incisors 8
      - Canines 4
      - Premolars 8
      - Molars 12
      - 32.
    - With the exception of the second and third molars the permanent teeth begin to develop about the sixteenth week of intrauterine life.
  - **Function** — To assist in the process of mastication.
- **Pharynx**
  - Muscular, membranous, cone-shaped tube between mouth and esophagus.
  - Three parts
    - Nasal or naso-pharynx — behind posterior nares above soft palate.
    - Oral — extends from soft palate to hyoid bone.
    - Laryngeal—extends from hyoid bone to esophagus.

- **Pharynx**
  - **Seven apertures**
    - 2 posterior nares.
    - 2 auditory tubes.
    - 1 fauces.
    - 1 larynx.
    - 1 esophagus.
  - **Nerves**
    - Receives fibers from both divisions of the autonomic system.
  - **Blood-vessels** — Branches from external carotid artery.
  - **Function**
    - Transmits air to larynx.
    - Serves as a resonating cavity.
    - Receives food and passes it to the esophagus.
- **Esophagus or Gullet**
  - Tube — 22.5–25 cm. long. Extends from pharynx to cardiac end of stomach.
  - **Four coats**
    1. Internal or mucous.
    2. Submucous or areolar.
    3. Muscular
       - Internal circular layer.
       - External longitudinal layer.
    4. External or fibrous.
  - **Nerves**
    - Vagus.
    - Thoracolumbar autonomic system.
  - **Blood-vessels**
    1. Inferior thyroid branch of the thyrocervical trunk.
    2. Branches from the thoracic aorta.
    3. Left gastric branch of celiac artery.
    4. Left phrenic branch of abdominal aorta.
  - **Function**
    1. Connects the pharynx with the stomach.
    2. Receives the food and passes it on to stomach.
- **Stomach, or Gaster**
  - Dilated portion of canal, size and shape vary.
  - Oblique position in epigastric, umbilical, and left hypochondriac regions, under the diaphragm.
  - **Openings**
    - Cardiac orifice — connects with esophagus.
    - Pyloric orifice — connects with duodenum.
    - Guarded by ring-like muscles known as sphincters.
  - **Curvatures**
    - Lesser curvature — concave border.
    - Greater curvature — convex border.
  - **Parts**
    - Fundus — blind end above the entrance of the esophagus.
    - Body — between fundic and pyloric portions.
    - Pyloric portion — smaller end.
  - **Four coats**
    1. Outer — serous — peritoneum.
    2. Muscular
       1. Longitudinal layer.
       2. Circular layer.
       3. Oblique layer chiefly at the cardiac end.
    3. Submucous — vascular.
    4. Mucous — rugæ.
  - **Glands**
    - Some cells of mucous membrane secrete secretin.
    - Cardiac — Secrete mucin.
    - Fundus
      - Chief or central cells secrete pepsinogen; parietal or oxyntic cells secrete acid.
    - Pyloric — Secrete pepsinogen and mucin.

Stomach, or Gaster

- **Nerves**
  - Thoracolumbar autonomic nerves from the celiac plexus.
  - Vagi nerves.
- **Blood-vessels** from three divisions of the celiac
  - Left gastric.
  - Hepatic.
  - Splenic.
- **Functions**
  1. Connects the esophagus with the intestine.
  2. Receives food in relatively large quantities about 3 times a day, holds it while it undergoes mechanical and chemical changes, then passes it on in small portions, at frequent intervals.
  3. Secretes mucin and gastric fluid.

Small, or Thin Intestine

- Convoluted tube extends from stomach to colic valve. About 7 m. long, coiled up in abdominal cavity.
- **Three divisions**
  - Duodenum — about 25 cm. (10 inches).
  - Jejunum — about 2.2 m. ($7\frac{1}{2}$ ft.).
  - Ileum — about 4 m. ($14\frac{1}{2}$ ft.).
- **Four coats**
  1. Serous from peritoneum.
  2. Muscular
     - Longitudinal layer.
     - Circular layer.
  3. Submucous — Connects the muscular and mucous coats.
  4. Mucous
     - Circular folds.
     - Villi — contain lacteals.
- **Glands and nodes**
  - Intestinal glands, Duodenal or Brunner's — Secrete intestinal fluid.
  - Lymph-nodules
    - Solitary.
    - Aggregated lymph-nodules called Peyer's patches.
- **Nerves**
  - Vagi supply sensory and motor fibers.
  - Thoracolumbar autonomic nerves derived from plexuses around superior mesenteric artery.
- **Blood-vessels**
  - Branches of the hepatic
  - Branches of the superior mesenteric — Distribute arched branches which lie between serous and muscular coats.
- **Functions**
  - Digestion.
  - Receives bile from liver, pancreatic fluid from pancreas.
  - Secretion of succus entericus. Duodenal cells secrete prosecretin. erepsin invertase maltase
  - Absorption.

Large, or Thick Intestine

- Largeness in width, not in length.
- Length, 1.5 m. (5 ft.); width, 6.3 cm. ($2\frac{1}{2}$ in.) to 3.5 cm. ($1\frac{1}{2}$ in.).
- Extends from ileum to anus.
- **Four parts**
  - Cecum, with vermiform appendix.
  - Colon
    - Ascending.
    - Transverse or mesial.
    - Descending.
    - Sigmoid.
  - Rectum — about 12 cm. (5 in.).
  - Anal canal — 3.5 cm. anus
    - External sphincter.
    - Internal sphincter.

- **Large, or Thick Intestine**
  - **Four coats**
    1. Serous, except that in some parts it is only a partial covering, and at rectum it is lacking.
    2. Muscular
       - Longitudinal layer — Arranged in three ribbon-like bands that begin at appendix, and extend to rectum.
       - Circular layer.
    3. Submucous.
    4. Mucous
       - No villi.
       - No circular folds.
       - Numerous
         - Intestinal glands.
         - Solitary lymph-nodules.
  - **Nerves** — Fibers from both divisions of the autonomic nervous system.
  - **Blood-vessels**
    - Superior mesenteric supplies the cecum, ascending and transverse colon.
    - Inferior mesenteric supplies the descending colon and rectum. Rectum also receives branches from hypogastric arteries.
  - **Function**
    - Continuance of digestion and absorption.
    - Elimination of waste.
- **Pancreas**
  - In front of first and second lumbar vertebræ, behind stomach.
  - **Hammer shape**
    - Head attached to duodenum.
    - Body in front of vertebra.
    - Tail reaches to spleen.
  - **Size**
    - About 12.5 cm. (5 in.) long.
    - About 5 cm. (2 in.) wide.
  - **Average weight** — 60–90 grams (2–3 oz.).
  - **Structure**
    - Compound gland—each lobule consists of one of the branches of main duct which terminates in cluster of pouches or alveoli.
    - Lobules held together by connective tissue form lobes.
    - Lobes form gland.
    - Duct from each lobule empties into pancreatic duct, also called duct of Wirsung.
    - Scattered throughout pancreas are islands of Langerhans.
  - **Function**
    1. Secretes pancreatic fluid — digestive fluid.
    2. Forms an internal secretion — aids in oxidation of glucose.
- **Liver**
  - Largest gland in body.
  - Location
    - Right hypochondriac.
    - Epigastric.
    - Left hypochondriac.
  - Convex above — fits under diaphragm.
  - Concave below — fits over right kidney, ascending colon, and pyloric end of stomach.
  - **Five ligaments**
    1. Falciform
    2. Coronary
    3. Right lateral
    4. Left lateral
       - (1–4) Formed by folds of peritoneum.
    5. Round ligament
       - Results from atrophy of umbilical vein.

Liver

- **Four Fossæ**
  - 1. Left sagittal fossa.
  - 2. Portal or transverse fossa transmits
    - Portal tube.
    - Hepatic artery.
    - Hepatic duct.
    - Lymphatics.
    - Nerves.
  - 3. Gall-bladder fossa.
  - 4. Fossa for inferior vena cava.
- **Four lobes**
  - 1. Right (largest lobe).
  - 2. Left (smaller and wedge-shaped).
  - 3. Quadrate (square).
  - 4. Caudate (tail-like).
- **Five sets of vessels**
  - 1. Branches of portal tube.
  - 2. Bile-ducts.
  - 3. Hepatic veins.
  - 4. Branches of hepatic artery.
  - 5. Lymphatics.
- **Nerves** — derived from the left vagus and the thoracolumbar autonomic system.
- **Blood-vessels**
  - Hepatic artery.
  - Portal tube.
  - Hepatic veins.
- **Anatomy of liver**
  - Hepatic cells are grouped in lobules.
  - Lobules 1.25–2.5 mm. in diameter.
  - Branches of portal tube
    - Interlobular veins (between lobules).
    - Intralobular capillaries (within lobules).
    - Sublobular veins (under lobules).
    - Hepatic veins — exit at portal fossa, empty into inferior vena cava.
  - Bile ducts
    - Channels between cells form intercellular biliary passages.
    - Interlobular ducts.
    - Hepatic duct — exit at portal fossa.
  - Branches of hepatic artery
    - Interlobular arteries (between lobules).
    - Intralobular capillaries (within lobules).
    - Course beyond the intralobular capillaries same as that pursued by blood from portal tube.
  - Lymphatics
    - Start in lobules, form network, and run from center to periphery.
    - Act as drain-pipes.
  - Glisson's capsule invests the liver.
  - Serous membrane from the peritoneum almost completely covers it.
- **Function**
  - 1. Bile-production.
  - 2. Glycogenic — glucose stored as glycogen, changed back to glucose as needed.
  - 3. Secretory
    - Forms an internal secretion which regulates the changing of glucose to glycogen and then to glucose again.

- **Liver**
  - **Function**
    - 4. Protective
      - (*a*) Waste products of protein digestion changed into substances that can be eliminated.
      - (*b*) Finishes disintegration of erythrocytes.
      - (*c*) Gives rise to antiprothrombin or heparin.
    - 5. Heat-formation.

- **Gall-bladder**
  - Pear-shaped sac lodged in gall-bladder fossa on under surface of liver.
  - **Size**
    - Three to four inches long.
    - One inch wide.
    - Capacity about nine drachms.
  - **Three coats**
    - 1. Mucous membrane.
    - 2. Fibrous and muscular tissue.
    - 3. Serous membrane from peritoneum.
  - **Function**
    - Serves as a reservoir for bile in intervals between digestion.
    - During digestion — pours bile into duodenum

CHAPTER XIX

FOOD; DIGESTION IN THE MOUTH, STOMACH, SMALL AND LARGE INTESTINES

Man's dependence on plants. — The proteins, carbohydrates, and fats found in food are comparable to the proteins, carbohydrates, and fats of which human tissues are composed. The chlorophyl-containing cells of plants utilize the energy of the sun's rays to synthesize carbon dioxide and water which they absorb from the air and soil, into carbohydrates. Using the carbohydrates as a basis, plants manufacture fats and with other salts, especially nitrates, they manufacture proteins. Consequently the life processes in plants are described as mainly constructive, but in man the life processes are destructive and constructive. In other words, man cannot synthesize simple substances like carbon dioxide, water, nitrates, etc., into carbohydrates, fats, and proteins, but instead splits up the carbohydrates, fats, and proteins of food into simpler substances, *i.e.*, simple sugars, glycerin and fatty acids, and amino-acids, and these standard substances the tissue cells can synthesize into the carbohydrates, fats, and proteins characteristic of their own tissues. All the processes concerned with the splitting up of carbohydrates, fats, and proteins into simple substances are termed **digestive processes,** and take place in the alimentary canal.

FOOD

Definition. — Food is any substance taken into the body, (1) to yield energy, (2) to build tissue, and (3) to regulate body processes.

(1) All the body activities require a certain amount of energy;[1] this and all the heat dissipated from the body must be supplied by food. The energy in food is present in the form of potential or latent energy, binding the atoms into molecules and the molecules into larger masses. The splitting of these complex molecules into smaller and simpler ones releases energy. Food material, over and above what is needed for this purpose, is stored in the

[1] Energy can be defined as the capacity or ability to do work.

body either in the form of fat, or as glycogen in the liver and muscles. This may be regarded as reserve fuel which, when needed, is oxidized to furnish energy.

(2) The material for the growth of the body is derived from food; also the material to make good the loss resulting from the daily wear and tear of body tissues.

(3) Nutrition and growth are dependent upon certain essential substances called vitamins. Water and inorganic salts are necessary to maintain the normal composition of the tissues.

Classification of food. — Chemical analysis shows that the chemical elements found in the body are also found in food. Various combinations of these elements give us a great variety of substances which are grouped as follows:

Nutrients or Food Principles:
- Water.
- Carbohydrates.
- Fats.
- Proteins.
- Ash constituents or mineral salts.
- Vitamins.

Water. — Water is a compound of hydrogen and oxygen. It constitutes about two-thirds of the daily intake, which gives it first place in the diet.

The water content of the body comes from three sources: (1) the water taken as a beverage or in other liquids, (2) the water contained in foods, especially vegetables and fruits, and (3) the water formed in the tissues as the result of the combustion of fuel foods.

Water enters into the composition of all the tissues, most tissues containing between 75 and 90 per cent. In actively growing tissues and in young animals there is a greater proportion than in less active tissues or in older animals. Water supplies fluid for the secretions and for the chemical changes occurring in digestion. Its most obvious services are in connection with the absorption of food in solution and the removal of dissolved wastes. By its evaporation from the skin and the respiratory passages it helps to keep the body temperature from rising above normal.

Under normal conditions the amount of water in the body remains about the same, even though the intake may vary considerably. If the amount of water is increased, the blood-pressure in the renal vessels is raised and the secretion of urine is stimulated. If the amount of water is decreased, the resulting sensation of thirst is so intolerable that steps are taken to relieve it. With few exceptions it is important to drink a liberal supply of water.

Carbohydrates. — Carbohydrates [2] are the most abundant and most economical sources of energy. They contain carbon, hydrogen, and oxygen, in the proportion of two atoms of hydrogen to one of oxygen.[3] All the simple sugars and all substances which can be converted into simple sugars by hydrolysis are carbohydrates. The names of these compounds suggest the number of simple sugar groups they will yield on hydrolysis.

The varieties of carbohydrates are: (1) monosaccharides, (2) disaccharides, and (3) polysaccharides.

Monosaccharides. — Monosaccharides, or simple sugars, contain one sugar group, $C_6H_{12}O_6$. They are soluble, and unless attacked by organisms in the alimentary canal, can be absorbed without further change. They are the units from which all the other carbohydrates are formed.

Monosaccharides	Glucose or dextrose, found in fruits, especially the grape, and in the blood.	$C_6H_{12}O_6$
	Fructose or levulose, found with glucose in fruits.	$C_6H_{12}O_6$

Disaccharides. — The formula, $C_{12}H_{22}O_{11}$, shows that disaccharides contain the same elements as monosaccharides, but they consist of two groups. During the process of digestion, they are changed to monosaccharides, either glucose or invert sugar, which consists of a molecule each of glucose and fructose. Only one splitting is necessary as one molecule of a complex sugar plus one molecule of water will form one molecule of glucose and fructose.

Disaccharides	Sucrose or cane sugar, found in vegetables, fruits, and juices of many plants.	$C_{12}H_{22}O_{11}$
	Lactose or milk sugar, found in the milk of all mammals.	$C_{12}H_{22}O_{11}$
	Maltose is an intermediate product in the digestion of starch, found in the body, in germinating cereals, malts, and malt products.	$C_{12}H_{22}O_{11}$

$$\underset{\text{DISACCHARIDE}}{C_{12}H_{22}O_{11}} + \underset{\text{WATER}}{H_2O} \longrightarrow \underbrace{\underset{\text{GLUCOSE}}{C_6H_{12}O_6} \cdot \underset{\text{FRUCTOSE}}{C_6H_{12}O_6}}_{\text{Invert Sugar}}$$

Polysaccharides. — Polysaccharides are represented by the molecular formula $(C_6H_{10}O_5)n$. The elements are present in the

[2] The International Union of Pure and Applied Chemistry has proposed the term *Glucides* as a group name for Carbohydrates.

[3] There is one carbohydrate, rhamnose, in which this proportion does not occur. There are also a number of compounds which are not carbohydrates, although they do contain carbon, hydrogen, and oxygen, the two latter in the proportion of two to one; hence this definition is not sufficient.

same proportion, but the value of n may be very large and is probably different for each polysaccharide. For instance, the value of n for the starch molecule is large, representing a large number of sugar groups, while for the dextrin molecule it is smaller, so that a single molecule of starch may be hydrolyzed into several molecules of dextrin of the same relative composition. In the disaccharides, only one splitting is necessary, as each molecule of a disaccharide plus one molecule of water will yield two molecules of a simple sugar. As the polysaccharides are so complex, they must pass through several stages before they are changed by hydrolysis to simple sugars. Each splitting of the molecule gives substances with simpler composition, though with the same relative proportion of the constitutents, and to each is given a special name. Thus as the result of the first splitting we have dextrin, of which there are two varieties, *i.e.*, erythrodextrin, and achroödextrin, each one being produced as a result of the further splitting of the molecules; then maltose, a disaccharide, is yielded, and finally glucose, a monosaccharide. The number of molecules of simple sugar resulting from the hydrolysis of any polysaccharide would depend upon the value of n.

Polysaccharides	Starch — found in grain, tubers, roots, etc.	$(C_6H_{10}O_5)n$
	Cellulose — outside covering of starch grains, and basis of all woody fibers.	$(C_6H_{10}O_5)n$
	Glycogen — form in which sugar is stored in the liver and muscles.	$(C_6H_{10}O_5)n$
	Dextrin — formed from starch by partial hydrolysis.	$(C_6H_{10}O_5)n$

Starch is the principal form in which carbohydrate is stored in plants. Three-fourths of the solids of ripe potatoes and one-half to three-fourths of the solid matter of the cereal grains is starch. During the ripening process in some plants, *e.g.*, apple and banana, starch is changed to glucose; in other plants, *e.g.*, corn and peas, the opposite process takes place.

Cellulose constitutes the supporting tissue of plant cells. When derived from mature plants, cellulose is quite resistant to the action of dilute acids or digestive enzymes, and passes through the digestive tract unchanged. The chief value of cellulose in human nutrition is to give bulk to the intestinal contents and thereby facilitate peristalsis.

Glycogen is the form in which reserve carbohydrate is stored in the animal body, in greatest quantity in the liver and muscles.

Dextrins are formed from starch by the action of enzymes, acids, or heat.

Fats. — The word fat[4] is sometimes used in an anatomic sense and sometimes in a chemical sense. In an anatomic sense, fat denotes adipose tissue. In a chemical sense, fats are glyceryl

[4] The International Union of Pure and Applied Chemistry recommends *Lipides* as a group name for fats and related substances.

esters[5] of fatty acids. In other words, fats are derived from the reaction of three molecules of fatty acid and one molecule of glycerin.[6] The ordinary fats of animal and vegetable food are not simple substances, but are mixtures of simple fats named palmitin, stearin, olein, etc., which are derived from the fatty acids — palmitic, stearic, and oleic. The reaction between three molecules of fatty acid and one molecule of glycerin in the formation of fat is as follows:

Organic Acid	+	Organic Base	⟶	Salt	+	Water
(STEARIC ACID)		(GLYCERIN)		(STEARIN)		(WATER)
$3\,H \cdot C_{18}H_{35}O_2$	+	$C_3H_5(OH)_3$	⟶	$C_3H_5(C_{18}H_{35}O_2)_3$	+	$3\,H_2O$

This reaction is comparable to the neutralizing of an inorganic acid by an inorganic base resulting in a salt and water.

$$\text{Acid} + \text{Base} \longrightarrow \text{Salt} + \text{Water}$$
$$HCl + NaOH \longrightarrow NaCl + H_2O$$

Under the influence of steam, mineral acids, and certain enzymes found in the body, fats split up into the substances of which they are built, *i.e.*, glycerin and fatty acids. Accordingly, the digestion of fats is a reaction in exactly the opposite direction:

Salt	+	Water	⟶	Base	+	Acid
(STEARIN)		(WATER)		(GLYCERIN)		(STEARIC ACID)
$C_3H_5(C_{18}H_{35}O_2)_3$	+	$3\,H_2O$	⟶	$C_3H_5(OH)_3$	+	$3\,H \cdot C_{18}H_{35}O_2$

The process of *saponification* is similar to the above, only that instead of water a base is used and the final products are glycerin and soap.

Salt	+	Base	⟶	Base	+	Soap
(STEARIN)		(POTASSIUM HYDROXIDE)		(GLYCERIN)		(SOAP)
$C_3H_5(C_{18}H_{35}O_2)_3$	+	$3\,KOH$	⟶	$C_3H_5(OH)_3$	+	$3\,K(C_{18}H_{35}O_2)$.

Fats are compounds of carbon, hydrogen, and oxygen, the same elements found in carbohydrates, but they are present in different combinations and proportions. The fats contain less oxygen and more carbon and hydrogen than the carbohydrates, consequently they are a more concentrated form of fuel.

Fats are insoluble in water, but are soluble in such fat solvents as ether, chloroform, and benzine.

Compound Fats.[7] — These are esters of fatty acids containing groups in addition to a base and a fatty acid. Examples of compound fats are:

[5] Esters are organic salts derived from the reaction of an acid and an organic base. They are analogous to the salts formed through the reaction of an acid and an inorganic base.

[6] Glycerin or glycerol is a triatomic alcohol.

[7] Compound fats are also called *lipoids*.

(1) *Phospholipids or phosphatids,* which contain both phosphorus and nitrogen. The best known are the lecithins, which are abundant in egg yolk and occur in brain and nerve tissue and in all the cells and tissues of the body.

(2) *Glycolipids or cerebrosides* are compounds of fatty acids with a carbohydrate, and contain nitrogen, but no phosphoric acid. Cerebrosides are found in the myelin sheath of nerves in connection with, possibly in combination with, lecithin.

(3) *Sterols* are solid alcohols, which are found in nature combined with fatty acids. They contain carbon, hydrogen, and oxygen. The best known is cholesterol, or cholesterin ($C_{27}H_{45}OH$), which is very widely distributed in the body, being found in the medullary coverings of nerve fibers, in the blood, in all the cells and liquids of the body, in the sebum secreted by the sebaceous glands of the skin, and in the bile. In the blood it protects the red cells against the action of hemolytic substances, and in the sebum it protects the skin. Under the influence of ultra-violet rays (direct sunlight or from a mercury vapor quartz lamp), cholesterol may be so changed as to acquire the property of an antirachitic vitamin. It is thought that the cholesterol of the bile is a waste product.

Proteins. — Proteins are more complex than either carbohydrates or fats and differ from them in having *nitrogen,* hence they are described as nitrogenous compounds. Proteins always contain carbon, hydrogen, oxygen, and nitrogen; sometimes sulphur, phosphorus, or iron is present.[8] Proteins are built up of simpler substances called amino-acids. Amino-acids are acids that contain an amino radical (NH_2) instead of a replaceable hydrogen atom.[9] If we take acetic acid, which is one of the simplest organic acids, we find the formula to be CH_3COOH. If one of the three hydrogen atoms in the CH_3 group is replaced by NH_2, we get a substance which has the formula $CH_2(NH_2)COOH$ and is called amino-acetic acid, glycine or glycocoll. Another organic acid is propionic acid which has the formula C_2H_5COOH; if we replace an atom of hydrogen by the amino group we obtain $C_2H_4(NH_2)COOH$, which is amino-propionic-acid or alanine.

[8] The elements occur in proteins in about the following percentages: carbon, 52%; oxygen, 22%; nitrogen, 16%; hydrogen, 7%; sulphur, 1%. Phosphorus, when present, amounts to about one per cent.

[9] Acids owe their characteristic properties to one or more hydrogen atoms that they hold in loose combination and part with in chemical reactions. The hydrogen atom is called replaceable because it is replaced by the elements or radicals which unite with the remainder of the molecule in action.

About eighteen amino-acids have been described. Various combinations of these amino-acids result in many different kinds of proteins which give different reactions and are represented by different formulæ.[10] The proteins of one animal differ from those of another, and the proteins of different kinds of tissue are not identical. This is also true of the proteins of plants. Hence we have the protein of milk, meat, fish, egg, cereal, and vegetables, all representing different combinations of the protein alphabet. The legumes — peas, beans, lentils, and peanuts, among vegetables — are especially rich in proteins.

Examples of protein constituents of food	*Albumin, e.g.*, the white substance seen when egg is heated; the scum that forms on the top of milk when its temperature is raised above 76° C. (170° F.), the white coating that forms on meat when it has been in a hot oven for a short time. *Caseinogen, e.g.*, the substance that is formed into a curd when acid or rennin is added to milk, or when milk sours. *Gluten, e.g.*, the gummy substance in wheat. *Legumin*, a protein substance contained in the legumes. *Gelatin*, from intercellular substance of connective tissues, including bones and tendons. *Organic extracts, i.e.*, protein substances formed in animals and plants as a result of their metabolism. The flavor of meats and some plant foods is due to extractives.

Classification. — Proteins are classified in three main groups:

1. Simple proteins consist only of amino-acids, and on hydrolysis yield only amino-acids or their derivatives.

2. Conjugated proteins are substances which contain the protein molecule united to some other molecule or molecules otherwise than as a salt. On hydrolysis they yield amino-acids and the other molecule. This molecule is nuclein in the nucleoproteins, a carbohydrate in the glycoproteins, a phospho-body in the phosphoproteins, pigment in the chromoproteins and hemoglobins, and a fatty substance in lecithoproteins.

3. Derived proteins are classified into two groups: (1) primary protein derivatives, and (2) secondary protein derivatives.

(1) Primary protein derivatives are derivatives of the protein molecule, apparently formed through hydrolytic changes, which involve only slight alterations of the protein molecule. Each

[10] It is difficult to convey an adequate impression of the complex fashion in which the five or six elements are combined. Many years ago the following formula was suggested for hemoglobin, the red protein of the blood, which is exceptional in containing iron:

$$C_{758}H_{1203}O_{218}N_{195}FeS_3$$

It is not seriously maintained that these large numbers are precisely correct, but the order of their magnitude is probably typical.

splitting of a protein molecule gives substances with simpler composition, and each one of these is given a special name; proteins split into metaproteins which in turn give coagulated proteins.

(2) Secondary protein derivatives are products of the further hydrolytic cleavage of the protein molecule. These are proteoses which on hydrolysis yield peptones and then peptides.

Ash constituents or mineral salts. — On page 19 the chemical elements that enter into the composition of the body are listed. Since all the substances in the human body are continually undergoing disintegration and renewal, it follows that every element shares in these processes. In other words, more or less of each element must be metabolized and eliminated daily, and if equilibrium is to be maintained, an equal amount must be supplied. Simple proteins furnish only five of the fifteen or more elements necessary to human nutrition; fats and carbohydrates are composed of but three of these five, water of but two. This leaves about ten elements to be furnished by some ingredients of food other than simple proteins, carbohydrates, and fats. These chemical elements are grouped as "ash constituents," "mineral salts," "minerals," or "inorganic foodstuffs." None of these terms is entirely appropriate.

These chemical elements exist in the body and take part in its functions in at least three ways: (1) as constituents of bone, giving rigidity to the skeleton; (2) as essential elements of the organic compounds which enter into the composition of the soft tissues; (3) as soluble salts held in solution in the fluids of the body — (*a*) giving these fluids their influence upon the elasticity and irritability of the muscles and nerves, (*b*) supplying material for the acidity or alkalinity of the digestive fluids, (*c*) helping to maintain the acid-base equilibrium of the body fluids as well as their osmotic pressure and solvent power. The importance of the right concentration of the mineral salts in the tissues and fluids of the body is so great that any considerable change from the normal endangers life. They are essential ingredients of nearly all substances used for food, but a diet that does not contain vegetables and fruit is quite certain to lack some of these salts, calcium and iron especially.

Vitamins. — Many nutrition experiments have made it evident that for growth and maintenance the human animal requires not only certain amounts of proteins, carbohydrates, fats, water, and inorganic elements, but certain other substances called *vitamins*. The metabolism of all the foodstuffs is influenced by the presence

or absence of vitamins. The chemical nature of the vitamins is not definitely known, and there is no generally accepted theory as to the way in which they take part in the metabolisms that they influence. The general indications seem to be that they act as hormones rather than as enzymes or foods. They are designated as Vitamin A, Vitamin B, Vitamin C, Vitamin D, Vitamin E, etc. Our knowledge of vitamins is largely based on the effects caused by their lack in the diet of laboratory animals.[11] Recent experiments are concerned with determining the optimum amounts of the vitamins and their physiological effects.

Vitamin A, or fat-soluble A. — Vitamin A stands for a substance (or a group of closely related substances) which are essential to growth and health. The probable formula is $C_{20}H_{30}O$. Originally it was supposed that there was only one fat-soluble vitamin, but newer work has demonstrated that three vitamins, A, D, and E, belong to this group. Each has its distinctive effect.

The effects of a diet deficient in vitamin A are (1) cessation of growth and (2) susceptibility to xerophthalmia or dry eyes. Xerophthalmia favors bacterial infection, with the result that animals deprived of this vitamin have sore, pus-filled eyes and a conjunctivitis that may result in blindness unless the vitamin is supplied in time. A similar disease has been described in children under conditions in which the diet lacked vitamin A, and the addition of this element to the diet was followed by quick relief. The xerophthalmia is only one phase of widespread weakening of the body tissues and increased susceptibility to infections of the lungs, skin, and bladder, also inflammation and the formation of pus in the ears, the sinuses, and the glands near the base of the tongue.

Milk, butter, egg yolk, and the green leaves of plants are sources of vitamin A. Carrots, tomato, banana, and sweet potato are rich in it. It occurs in cod-liver oil and certain organs such as liver, kidneys, and sweetbreads. It does not occur in oleomargarine or in vegetable oils.

Vitamin B (B, antineuritic, and G, antipellagric vitamins). — The effects produced by a lack of vitamin B have led to repeated

[11] The composition of foods is important, but of even greater importance is the utilization of these foods by the body, as determined by feeding experiments. Experimentation on human beings must be limited. Laboratory animals, such as the rat, have been found to be satisfactory for such experiments. The rat of the nutrition laboratory resembles man in his environment, in his feeding habits, and in the chemical nature of his nutritive processes. In addition, the cycle of development takes place about thirty times as rapidly in the rat as in man, which makes it possible to observe the entire life of the animal within a comparatively brief period. For these and many other reasons, the rat can be used for nutrition experiments, the findings of which are to be applied to human problems.

suggestions that we are dealing with two vitamins. Recent work confirms this and indicates that vitamin B consists of two or more fractions, which it is proposed to call vitamins B and G. Vitamin B (probable formula $C_{12}H_{17}N_3OS$) is used for the less heat-resisting fraction, which has a pronounced effect in stimulating appetite and whose absence or deficiency in the diet is followed by symptoms of beri-beri or polyneuritis and by imperfect growth. Vitamin G is the more heat-resisting fraction, whose absence or deficiency is thought to be one factor in producing pellagra. Both B and G are essential to normal growth.

Beri-beri occurs chiefly among Oriental nations that make great use of rice as food. The disease takes a variety of forms, but the symptoms are gastrointestinal disturbances, paralysis, and atrophy of the limbs. This condition is caused by limiting the diet to polished rice. If the polishings are restored to the diet the condition disappears; or if meat or barley is used with the polished rice, the condition is avoided.

Pellagra[12] occurs in southern Europe, Italy, India, and Central America. The chief symptoms are (1) gastrointestinal, *i.e.*, a painful sore mouth, chronic diarrhea, sometimes nausea and vomiting; and (2) a typical rash, which usually occurs on the back of the hands.

The nervous symptoms are headache, dizziness, sleeplessness, and depression. Mental symptoms may also develop.

The principal source of vitamin B is the seeds of plants and the eggs of animals, which suggests that it is a provision for the needs of the growing plant or animal. It is also found in milk and is abundant in green vegetables such as spinach, leaves of turnips or beets, radishes, water cress, lettuce, and yeast. In the cereals it is found mainly in the germ and in the albuminous cells under the outside membrane (pericarp). In the process of milling, both these structures are removed from the best wheat flours, corn meal, rice, etc., hence they are deficient in this vitamin.

Vitamin C (*antiscorbutic vitamin*). — Probable formula is $C_6H_8O_6$. The records of sea voyages contain many accounts of epidemics of scurvy, which occurred when the diet lacked fresh meat and vegetables. Usually, in time of famine and war, scurvy is prevalent. During the Great War, scurvy was reported from Austria and Russia. This condition can be prevented or cured by the use of fresh vegetables or meat, or the juice of citrus fruits (lemons and oranges). These facts have been confirmed by many feeding experiments on laboratory animals and men. It is now recognized that scurvy is due to the lack of the antiscorbutic vitamin in the diet. This vitamin occurs in the leafy parts of

[12] See *Pellagra* by Vernon E. Powell in the *American Journal of Nursing*, March, 1931.

vegetables (cabbage, lettuce, and rutabaga), and in fresh fruits, particularly the juice of oranges, lemons, and tomatoes. It is the least resistant of the vitamins, as heating, drying, and other methods of preserving usually destroy it. This destruction does not occur in the absence of oxygen, or the presence of acids. Pasteurization of milk destroys vitamin C, hence the giving of orange juice or other antiscorbutics to children living on it. The juice of canned tomatoes is equally effective and less expensive.

The symptoms of scurvy are loss of weight, pallor, weakness, breathlessness, palpitation of the heart, swelling of the gums, loosening of the teeth, pains in the bones and joints, edema, nervousness, and slight hemorrhages appearing as red spots under the skin and forming hidden bleeding places in the muscles and internal organs. The heart hypertrophies and shows degenerative changes, which often cause sudden death.

Vitamin D (*antirachitic vitamin*). — This vitamin is related to the maintaining of the proper concentration of calcium and phosphorus in the body fluids and their deposition in bone. The experiments of Dr. McCollum [13] and his co-workers indicate that the wonderful efficiency of cod-liver oil in the prevention and cure of rickets is due to a specific vitamin other than vitamin A, to which they have given the name vitamin D. This vitamin is found in largest amounts in cod-liver oil, other fish liver oil, and in smaller amounts in egg yolk. Direct sunlight, ultra-violet light from mercury vapor lamp, and irradiated ergosterol are also preventive and curative for rickets but their use should be controlled by the physician.

Vitamin E (*antisterility vitamin*). — Sterility in rats may be produced by a diet which contains vitamins A and B and is adequate for growth. This sterility can be overcome by adding certain articles such as lettuce, meat, cereals, liver, or egg yolk to the diet. These foods contain vitamin E, which is thought to be necessary for the normal course of pregnancy.

Accessory articles of diet. — In addition to the foodstuffs proper, our foods contain numerous other substances which add to the attractiveness of food, stimulate appetite, and increase the secretion of gastric fluid. These substances may be classified under the heads of:

Flavors — Condiments: the various oils or esters that give odor and taste to foods. Salt, pepper, mustard, etc.

Stimulants: tea, coffee, cocoa, meat extracts, alcohol, etc.

[13] McCollum, E. V., *The Newer Knowledge of Nutrition.*

DIGESTIVE PROCESSES

In a broad sense all the processes by which foods are rendered available to an organism are digestive processes. In this sense, many industrial and domestic processes are in line with digestion and often initiate the task which the digestive organs complete. This is particularly true of cooking, for by it various changes are brought to pass; such, for example, as changing starch to dextrin, partially splitting fats into glycerin and fatty acids, and changing some proteins to the first stages of their decomposition products. A second reason for classifying cooking as a digestive process is that the appearance, odor, and taste of food are improved and these changes stimulate the end-organs of the optic and olfactory nerves, and the taste buds, causing a reflex stimulation of the digestive mechanisms. In a third way cooking may profoundly aid digestion by killing parasites or organisms which otherwise would gain a foothold in the alimentary canal and thus modify or change digestive processes. Digestive processes within the body may be described as mechanical and chemical.

The digestive processes are controlled by the nervous system. Any severe strain or strong emotion which affects the nervous system unpleasantly, inhibits the secretion of the digestive fluids and interferes with digestion, often checking the appetite and even preventing the taking of food. On the other hand, pleasurable sensations aid digestion, hence the value of attractively served food, pleasant surroundings, and cheerful conversation.

Mechanical digestion. — Under this heading the various physical processes that occur in the alimentary canal are included. It is to be considered as preliminary to chemical digestion. It serves the following purposes: (1) in taking food in and moving it along through the alimentary canal just rapidly enough to allow the required chemical changes to take place in each part; (2) in lubricating the food by adding the mucin and water secreted by the glands of the alimentary canal; (3) in liquefying the food by mixing it with the various digestive fluids; and (4) in separating the food into small particles, thereby increasing the amount of surface to come in contact with the digestive fluids.

The mechanical processes consist of:

1. Mastication.
2. Deglutition or swallowing.
3. Peristaltic action of the esophagus.
4. Movements of the stomach.
5. Movements of the intestines.
6. Defecation.

Chemical digestion. — An essential part of digestion is chemical and is a process of hydrolysis which is dependent upon the presence of enzymes. The term hydrolysis means a decomposition or splitting of a compound into simpler compounds through a chemical reaction with water. An example of hydrolysis is the conversion of any of the complex sugars into simpler sugars.

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 \cdot C_6H_{12}O_6$$

Necessity for chemical digestion. Chemical digestion is necessary because foods, with the exception of simple sugars, cannot diffuse through animal membranes, and the tissues cannot use them, hence they must be reduced to smaller molecules and to such standard substances as the tissues can use, *i.e.*, (1) simple sugars, resulting from the hydrolysis of all carbohydrate foods; (2) glycerin and fatty acids, resulting from the hydrolysis of fats; and (3) amino-acids, resulting from the hydrolysis of proteins.

Cause of chemical digestion. — Hydrolytic cleavages[14] similar to those of digestion can be brought about in several ways. Boiling foodstuffs with acids, treatment with alkalies, or the application of superheated steam will accomplish these changes. The remarkable fact is that violent reagents, high temperatures, or both are necessary to produce these changes in the laboratory, whereas in the digestive tract they take place at body temperature and are due to the enzymes present in the digestive fluids. Enzymes have been described (page 339) as organic substances that act as catalysts.

Classification of enzymes. — It has been suggested that each hydrolytic enzyme be designated by the name of the substance on which it acts (substrate), together with the suffix, *ase.* According to this, the starch-splitting enzymes are called *amylases;* fat-splitting enzymes, *lipases;* protein-splitting enzymes, *proteases.* This suggestion has been followed in part only, as the older names continue to be used, *e.g.*, pepsin, rennin, trypsin, etc.

The following classification is a modification from W. H. Howell's *Textbook of Physiology.*

1. The sugar-splitting enzymes. (*a*) The inverting enzymes, which hydrolyze disaccharides to monosaccharides. Examples: Maltase splits maltose to dextrose; invertase splits cane-sugar to dextrose and levulose; and lactase splits milk-sugar (lactose) to dextrose and galactose. (*b*) The enzymes which split the monosaccharides. Enzymes capable of splitting glucose of the tissues into lactic acid.

[14] It is to be noted that the hydrolytic enzymes are the ones that bring about digestive changes.

2. The amylolytic or starch-splitting enzymes. Examples: Ptyalin or salivary diastase, amylase, or pancreatic diastase cause hydrolysis of starch.
3. The lipolytic, or fat-splitting enzymes. Example: Lipase found in the pancreatic secretion, etc., causes hydrolysis of fat.
4. The proteolytic or protein-splitting enzymes. Examples: Pepsin of gastric fluid, trypsin of pancreatic fluid which cause hydrolysis of the proteins.
5. The clotting enzymes, which convert soluble to insoluble proteins. Example: The clotting of the casein of milk by rennin.
6. The oxidizing enzymes, or oxidases. Enzymes which cause oxidation.
7. The deaminizing enzymes. All amino-acids contain an NH_2 group which is split off by hydrolysis.

CHANGES THE FOOD UNDERGOES IN THE MOUTH

Mastication. — When solid food is taken into the mouth, it is cut and ground by the teeth, being pushed between them again and again by the muscular contractions of the cheeks, and the movements of the tongue, until the whole is thoroughly crushed.

Insalivation. — During the process of mastication saliva is poured in large quantities into the mouth, and mixing with the food, lubricates, moistens, and reduces it to a softened mass known as a bolus.

Secretion of saliva. — The nerve supply of the salivary glands is derived in part from the craniosacral and in part from the thoracolumbar divisions of the autonomic system. Both sets of nerves carry secretory and vasomotor fibers. The cranial nerves carry vasodilator fibers, and when stimulated by the sight or smell of food, (*a*) dilate the blood-vessels, increasing the volume and temperature of the gland, and (*b*) produce a secretion that is copious in amount and watery in consistency. This is called a psychical secretion. The thoracolumbar nerves carry vasoconstrictor fibers, and when stimulated by the presence of food in the mouth, (*a*) constrict the blood-vessels and (*b*) produce a smaller amount of thicker secretion. Under normal conditions, the flow of saliva is the result of reflex stimulation of the secretory nerves. Obviously, the taste buds of the tongue, fauces, and cheeks are the sense organs which are stimulated by the presence of food in the mouth.

Saliva. — Saliva consists of a large amount of water, holding in solution some protein material, mucin, inorganic salts, an enzyme called *ptyalin,* and one called *maltase.* It has a specific gravity of about 1.004, and is nearly neutral in reaction (pH 6.6 to 7.1).

The functions of saliva. — These functions are: (1) to soften and moisten the food, assisting in mastication and deglutition; (2) to coat the food with mucin, lubricating it and insuring a smooth

passage along the esophagus; (3) to dissolve dry and solid food, providing a necessary step in the process of stimulating the taste buds as taste sensations play a part in the secretion of gastric juice; and (4) to digest starch by means of ptyalin.

Ptyalin and maltase. — Ptyalin changes starch to dextrin and maltose; the latter may be further digested to glucose by *maltase*, a second enzyme found in the saliva. The process of reducing starch is a complicated one, consisting of a series of hydrolytic changes which take place in successive stages, and result in a number of intermediate compounds. The change is best effected at the temperature of the body,[15] in a neutral solution, saliva that is distinctly acid hindering or arresting the process. Boiled starch is changed more rapidly and completely than raw, but food is rarely retained in the mouth long enough for the saliva to do more than begin the digestion of starch.

Deglutition or swallowing. — The act of swallowing is divided into three stages, which correspond to the three regions, — mouth, pharynx, and esophagus, — through which the food passes. The *first stage* consists of the passage of the bolus of food through the fauces. The *second stage* consists of the passage of the bolus through the pharynx. During this stage, the respiratory opening into the larynx is closed by the approximation of the vocal folds which close the glottis, and by the elevation of the larynx. Two views are held regarding the movements of the epiglottis, (1) that it is pressed down upon the glottis and (2) that it is not necessary for it to be pressed down. The parts are crowded together by the descent of the base of the tongue, by the lifting of the larynx, and the coming together of the vocal folds.

The *third stage* consists in the passage of the bolus through the esophagus. Apparently the consistency of the food affects this stage of the process. Solid or semi-solid food is forced down the esophagus by a peristaltic movement, and requires from four to eight seconds for its passage from mouth to stomach. About half of this time is taken up in the passage through the esophagus, and the remainder is spent in transit through the cardiac orifice of the stomach. Liquid or very soft food is shot through the esophagus and arrives at the lower end in about 0.1 second. It may pass into the stomach at once, or may be held in the esophagus for some moments, depending on the condition of the cardiac sphincter.

[15] A temperature of 100° F. (37.7° C.) in the alimentary canal is necessary for digestion, hence iced drinks or iced foods that lower this temperature delay digestion.

When the stomach is empty, the cardiac sphincter is probably relaxed. As digestion continues, the sphincter becomes more tense. The tension develops in response to the rise of acidity in the liquid, just within the cardiac portion of stomach.

Summary. — During the process of mastication, insalivation, and deglutition the food is reduced to a soft, pulpy condition, any starch it may contain begins to be changed into sugar, and it acquires a more or less alkaline reaction.

Vomiting. — Under ordinary circumstances the contractions of the cardiac sphincter prevent the regurgitation of food, but spasmodic contractions of the abdominal muscles may, if the diaphragm is fixed, force the contents of the stomach through the esophagus and mouth to the exterior. This is called vomiting. It is usually preceded by a sensation of nausea and a reflex flow of saliva.

CHANGES THE FOOD UNDERGOES IN THE STOMACH, OR STOMACH DIGESTION

The food which enters the stomach is delayed there by the contraction of the sphincter muscles at the cardiac and pyloric openings. The cavity of the stomach is always the size of its contents, which means that when there is no food in it, it is contracted, but when food enters, it expands just enough to hold it. An investigator fed rats with foods of different colors and found that the portions which had been eaten successively were arranged in definite layers. The food first taken lay next to the wall of the stomach, and filled the pyloric region, while the succeeding portions were arranged regularly in the interior in concentric layers. This was interpreted as evidence that the cavity of the stomach is only as large as its contents. The first portion of food entirely filled it, and successive portions were received into the interior because the wall layer was occupied. Within a few minutes after the entrance of food small contractions start in the middle region of the stomach and run toward the pylorus. These contractions are regular and in the pyloric region become more forcible as digestion progresses. As a result of these movements the food in the prepyloric and pyloric portions is macerated, mixed with the acid gastric fluid, and reduced to a thin liquid mass called **chyme.** At certain intervals the pyloric sphincter relaxes and the wave of contraction forces some of the chyme into the duodenum. The fundic end of the stomach is less actively concerned with these movements, but serves as a reservoir for food which is under slight

pressure, as the muscles are in a state of continual contraction or tone. Due to the lack of movement and the muscular tone, the food at the fundic end may remain undisturbed for an hour or more, and thus escape mixture with the gastric fluid, which cannot penetrate to the interior of the mass. Salivary digestion may continue during this time. As the chyme is gradually forced into the duodenum, the pressure of the fundus forces the food into the pyloric end.

The stomach can receive a large amount of food within a short period of time. It reduces this food to chyme and at intervals charges the intestine with small amounts of this chyme in such condition as to allow rapid digestion. It seems probable that without the stomach, our mode of eating would have to be changed, as it would not be possible to load the intestine with the amount of food ordinarily consumed at a meal.

Time required for stomach digestion. — It is obvious that the time required for gastric digestion depends upon the nature of the food eaten. Small test meals may be digested in from one to four hours, but average meals may take from five to seven hours. The ejection of chyme through the pylorus occurs at regular intervals, and is supposed to depend upon the consistency and acidity of the chyme. Solid particles forced against the pylorus tend to keep it closed, but a finely divided condition of the chyme and acidity produce relaxation of the pyloric sphincter. In the intestines hydrochloric acid has a contrary effect, as it causes a contraction of the sphincter, which remains closed after each ejection until the acidity has been neutralized.

Secretion of gastric juice. — The secretion of gastric fluid is constant. Even in the period of fasting there is a small continuous secretion, but during the act of eating and throughout the period of digestion, the rate of secretion is greatly increased.

In an ordinary meal the secretion first started is due to the sensations of eating and the taste and odor of food, which stimulate the sensory end-organs in the mouth and nose. This so-called psychical secretion insures the beginning of gastric digestion, and is supplemented by chemical action arising in the stomach. Some foods, such as meat juices and extracts, contain substances called secretagogues or hormones which are supposed to act directly upon the nerves of the pyloric mucous membrane and form a substance called *gastrin* or *gastric secretin*, which is absorbed into the blood and carried to the gastric glands. This substance stimulates the glands to secretion. Other foods, such as milk, bread, white of egg, etc.,

do not appear to contain secretagogues. When such foods are eaten, a psychical secretion is started and when this has acted, some products of their digestion in turn become capable of stimulating a further secretion of gastric fluid. These three steps are (1) psychical or appetite secretion, (2) the secretion from secretagogues contained in the food, and (3) the secretion from secretagogues contained in the products of digestion.

Gastric fluid. — Gastric fluid is secreted by the gastric glands lining the mucous membrane of the stomach. It is a thin, colorless, or nearly colorless liquid with an acid reaction (pH is about 1.67) and a specific gravity of about 1.002–1.003. The quantity secreted depends upon the amount and kind of food to be digested. Upon analysis it is found to be a watery secretion containing some protein, some mucin, and inorganic salts, but the essential constituents are hydrochloric acid and two or possibly three enzymes — pepsin, rennin, and gastric lipase.

Hydrochloric acid. — It is generally believed that the parietal or oxyntic cells of the gastric glands secrete the hydrochloric acid, from chlorides found in the blood. The chief chloride is sodium chloride, and by some means this is decomposed; the chlorine combines with hydrogen, and is then secreted upon the free surface of the stomach as hydrochloric acid. In normal gastric fluid it is found in the proportion of about 0.2 per cent. It serves (1) to activate pepsinogen and convert it to pepsin; (2) it provides an acid medium which is necessary for the pepsin to carry on its work; (3) it swells the protein fibers, thus giving easier access to pepsin; (4) it helps in the inversion of cane-sugar, which is the easiest of the disaccharides to invert; (5) it acts as a disinfectant and may kill organisms that enter the stomach, and (6) it helps to regulate the opening and closing of the pyloric sphincter.

If the secretion of hydrochloric acid is excessive, it causes hyperacidity of the gastric fluid, which is one of the underlying causes of gastritis and gastric ulcer.

Pepsin. — Pepsin is supposed to be formed in the pyloric glands and the chief cells of the gastric glands. It is present in these cells in the form of a zymogen, an antecedent inactive substance called propepsin or pepsinogen which is quickly changed to active pepsin by the action of hydrochloric acid.

Pepsin is a weak proteolytic enzyme requiring an acid medium in which to work. It has the property of hydrolyzing proteins through several stages into proteoses and peptones. This action

is preparatory to the more complete hydrolysis that takes place in the intestines under the influence of trypsin and erepsin, for peptones are not absorbed but undergo a further hydrolysis to amino-acids.

Rennin. — Rennin, like pepsin, is supposed to be formed in the chief cells of the gastric glands in a zymogen form, the *prorennin,* which after secretion is converted to the active enzyme. So far as is known, this enzyme acts *only* upon the soluble protein of milk, which is called *casein.* It converts this substance into paracasein which reacts with calcium to form the curd, the digestion of which is carried on by the pepsin, and later, in the intestine, by the trypsin.

Various observers have described other enzymes in addition to the pepsin and rennin, but the evidence regarding these is uncertain. It is probable that the ptyalin swallowed with the food continues the digestion of starchy material in the fundus for some time. Regarding the fats, it is believed that they undergo no true digestive change in the stomach. They are set free from their mixture with other foodstuffs by the dissolving action of the gastric fluid; they are liquefied by the heat of the body, and are scattered through the chyme in a coarse emulsion by the movements of the stomach, all of which favors the subsequent action of the pancreatic fluid. Emulsified fats like cream are acted upon to a limited extent by a third enzyme called *gastric lipase,* but the acid condition of the stomach contents prevents any considerable change of this sort.

Summary. — The stomach serves as (1) a place for temporary storage and maintains a gradual delivery to the intestine; (2) a place for (*a*) the continuation of the salivary digestion of starch, (*b*) the beginning of the digestion of proteins and perhaps fats, and (*c*) germicidal activity — this is of doubtful value, because it is only while the food is in the pyloric region that it is subjected to the acidity of the gastric fluid.

Inhibition of gastric digestion. — The secretion of gastric fluid is inhibited by stimulation of the thoracolumbar system, so that anger, pain, worry, and also a distaste for food may delay digestion. Secretion is also inhibited by active exercise soon after a meal, because active exercise increases the amount of blood in the skeletal muscles, and decreases the supply to the stomach. When gastric digestion is much delayed, bacteria are likely to cause fermentation of the sugars, producing gas which may cause distress.

CHANGES THE FOOD UNDERGOES IN THE SMALL INTESTINE

The chyme, entering the duodenum, after an ordinary meal, is a mixture of various matters. Normally it is free from coarse particles and is acid in reaction, both the hydrochloric acid and the lactic acid produced by fermentation contributing to this. Much of the food is undigested. The proteins are partly peptonized; and some progress has been made in reducing cooked starch; fats have been liquefied and scattered but not extensively hydrolyzed. If milk was part of the diet, it will have been curdled and redissolved. It is in the intestines that this mixture undergoes the most profound digestive changes. These changes which constitute intestinal digestion are effected by: (1) the movements of the intestines, (2) the pancreatic fluid, (3) the succus entericus or secretion of the intestinal glands, and (4) the bile.

It is convenient to describe the secretion and digestive action of these three fluids separately, but it must be remembered that they act simultaneously.

Movements of the small intestine. — The movements of the small intestine are of two kinds: (1) peristaltic and (2) rhythmical.

(1) A peristaltic movement may be defined as a quick succession of waves of contraction passing slowly along the intestine. The purpose is to pass the food slowly forward.

(2) The rhythmical movements consist of a series of local constrictions of the intestinal wall which occur rhythmically at points where masses of food lie. The purpose of these constrictions is to divide the string of food into a number of equal segments. Within a few seconds each of these segments is halved and the corresponding halves of adjoining segments unite. Again constrictions recur and these newly formed segments are divided, and the halves re-form. In this way every particle of food is brought into intimate contact with the valvulæ conniventes and is thoroughly mixed with the digestive fluids.

Secretion of pancreatic fluid. — Pancreatic secretion, like gastric secretion, consists of two parts: (1) a nervous secretion, caused by the secretory fibers in the vagus and splanchnic; (2) a chemical secretion, due to the action of a hormone, *secretin*. Two views are held regarding secretin. One is that the acid of the gastric fluid, upon reaching the duodenum, produces secretin, which is absorbed by the blood, carried to the pancreas, and stimulates the pancreas to secrete. Another view is that the secretin exists, in the mucous

membrane of the duodenum (or jejunum), and is liberated by the bile, which pours into the intestine during gastric digestion. The bile salts, as they are absorbed, carry the secretin into the blood, and in this way it reaches the pancreas. It is thought that the nervous secretion provides pancreatic fluid in the early stages of intestinal digestion, and that the chemical secretion maintains the flow until all the stomach contents reach the duodenum.

Pancreatic fluid. — The *nervous secretion* of pancreatic fluid is thick, and rich in enzymes and proteins. The trypsin in it may be active. The *chemical secretion* is thin, watery, contains little enzyme or proteins, and is alkaline. Pancreatic fluid contains three groups of enzymes. Due to these enzymes, it has the power of acting on proteins, carbohydrates, and fats.

The proteolytic enzymes. — Under favorable conditions, the proteolytic action of pancreatic juice may break down the protein molecule to its constituent amino-acids. It was formerly thought that one enzyme — *trypsin* — produced this effect. It is now thought that two or three forms of proteolytic enzymes are necessary, and that they act at different stages of protein decomposition. At present there is no agreement regarding the number of enzymes or their precise mode of action. It is probable that at least three take part, namely, *trypsin*, *trypsin-kinase*, and *erepsin*. It has been thought that trypsin was secreted in the form of a zymogen called trypsinogen, and was activated by enterokinase, an enzyme which is contained in the mucous membrane of the small intestine. Later views indicate that enterokinase acts as a co-enzyme rather than as a kinase.

In the pancreatic secretion found in the intestine, both trypsin and trypsin-kinase occur. Each is proteolytic, but they act upon different substrates. The pepsin of the gastric fluid and the trypsin-kinase of the pancreatic fluid hydrolyze complex proteins to peptones. Peptones are hydrolyzed by trypsin and trypsin-kinase, and erepsin completes the hydrolysis to amino-acids.

The erepsin of the pancreatic fluid seems to be identical with the erepsin of the intestinal secretion. It belongs to the class of enzymes that act upon the simpler peptids, hydrolyzing them to amino-acids. The conditions under which enzymes act and the length of time they are allowed to act determine the actual products that result.

The amylolytic enzyme (*amylase*). — The action of amylase is similar to that of ptyalin. It causes hydrolysis of starch with the production of maltose. The starchy food that escapes digestion

in the mouth and stomach becomes mixed with this enzyme and continues under its action until the colic valve is reached. Maltose is further acted upon by the maltase of the intestinal secretion and converted to dextrose.

The lipolytic enzyme (*lipase*). — Lipase is an enzyme capable of hydrolyzing fats to glycerin and fatty acids, and of saponifying them to form soaps. The process of hydrolysis is preceded by emulsification[16] which is dependent upon the formation of soaps. The lipase splits some of the fats to fatty acids and glycerin. The fatty acids combine with the alkaline salts to form soaps (saponification). This soap causes the emulsification of the fat. Emulsification increases the surface of fat exposed to the chemical action of the lipase and is a mechanical preparation for the further action of lipase. The glycerin and fatty acids produced by the action of the lipase are absorbed by the epithelium of the intestine. It is thought that the fatty acids form soluble and diffusible compounds with the bile salts and are absorbed in this form. After absorption the fatty acids and glycerin again combine to form fat, but it is probable they combine in such proportions as to make fat characteristic of man. The action of lipase is said to be reversible, *i.e.*, it causes both the splitting of the fats and the synthesis of the split products, not only in the intestines, but in the various tissues, during the metabolism or the storage of fat. Lipase is found in blood and in many of the tissues.

The intestinal secretion (succus entericus). — This is a clear, yellowish fluid which has a marked alkaline reaction, due to the presence of sodium carbonate. Extracts of the walls of the small intestine have been found to contain four or five enzymes which influence intestinal digestion to a marked extent. The enzymes are to be found in the secretion. These enzymes and their actions are as follows:

Enterokinase is an enzyme or co-ferment which activates the trypsin of the pancreatic fluid.

Erepsin is an enzyme which hydrolyzes peptids to amino-acids, thus completing the work begun by the pepsin and trypsin.

Inverting enzymes are three in number and convert disaccharides into monosaccharides. (1) Maltase acts upon the products formed in the digestion of starches, *i.e.*, maltose and dextrin, and converts them to dextrose. (2) Invertase or sucrase acts upon sucrose and

[16] An oil emulsion contains minute globules of oil that do not coalesce. Emulsions may be made by shaking oil in a solution of soap, etc. Milk is a natural emulsion. On standing it slowly separates as the fat rises to the top and forms cream.

changes it to dextrose and levulose. (3) Lactase acts upon lactose and changes it to dextrose and galactose. This inverting action is necessary because disaccharides cannot be used by the tissues and would escape in the urine, but in the form of simple sugars they are readily used by the tissues.

Nuclease is the name given to an enzyme which is said to occur in the small intestine. It acts upon the nucleic-acid component of nucleoproteins.

Secretin is not an enzyme but a hormone which is secreted or formed in the intestinal mucosa. Under the influence of acids or of acids and bile, it is absorbed, carried to the pancreas, and causes a flow of pancreatic fluid.

Bile. — Bile is formed in the liver, and is an alkaline fluid the specific gravity of which varies from 1.010 to 1.050. It is usually yellow, brownish yellow, or olive green in color.[17] It consists of water, bile pigments, bile acids, bile salts, cholesterol, lecithin,[18] neutral fats, and soaps. The bile acids are glycocholic and taurocholic, occurring as sodium glycocholate and sodium taurocholate. These salts are alternately excreted into the duodenum, then reabsorbed and reappear in the bile. Thus, by continued circulation, the bile repeats its function many times. The mucous membranes of the bile ducts and gall-bladder secrete a mucilaginous protein called nucleo-albumin, which is added to the bile and causes it to be ropy and mucilaginous.

Secretion of bile. — The secretion of bile is continuous, but the amount varies, increasing when the blood flow is increased and vice versa. It is thought that the presence of bile in the intestines stimulates secretion in the liver, and is due to the bile-salts which act as cholagogues. Bile enters the duodenum only during the period of digestion. Between these periods it cannot enter the duodenum because of the sphincter which closes the common bile-duct; consequently the bile backs up into the gall-bladder. Apparently the ejection of chyme into the duodenum excites a contraction of the gall-bladder and an inhibition of the sphincter which results in an ejection of bile. The physiological effects of bile may be grouped as follows:

1. *Digestive secretion.* — Bile aids the action of lipase. Mixtures of bile and pancreatic fluid split the fats more rapidly than pancreatic fluid alone. The bile acids may activate the lipase, or may

[17] The color of bile is determined by the respective amounts of the bile pigments: (1) biliverdin, and (2) bilirubin, that are present.

[18] The cholesterol and lecithin are compound fats.

act as a co-ferment, and they help in the absorption of the fatty acids.

2. *Excretion.* — The bile is an excretory channel for toxins, metals, and cholesterol. It is thought that the liver cells excrete the bile pigments that are brought to them by the blood, just as the kidney cells remove the urea from the blood. The cholesterol of bile is probably a waste product of cellular disintegration.

3. *Antiseptic.* — It has a feeble and questioned antiseptic action upon the intestinal contents, and its presence limits putrefaction to some extent.

Gall-stones. — Cholesterol may become so concentrated in the gall-bladder that it tends to crystallize out, and these crystals form gall-stones. Catarrhal conditions, which are often due to the typhoid and colon bacilli, or to a change in the character of the bile, may cause this crystallization. Gall-stones are usually formed in the gall-bladder. Their passage through the cystic and common bile ducts often causes severe pain, called gall-bladder colic. They may plug the duct and cause jaundice.

Jaundice. — When the flow of bile through the bile-duct is interfered with, bile gets into the blood, and is carried to all parts of the body, producing a condition of jaundice, which is characterized by a yellow discoloration of the skin and of the whites of the eyes. The urine is of a greenish hue because of the extra quantity of pigment eliminated by the kidneys, and the stools are grayish in hue, due to the lack of bile. Gall-stones in the gall-bladder or ducts, plugging of the ducts with mucus, and constipation, may interfere with the excretion of bile.

Action of organisms in small intestine. — Numerous organisms which are able to hydrolyze carbohydrates and proteins are constantly present in the small intestine. Fermentation of the carbohydrates gives rise to organic acids, such as lactic and acetic, but none of the products of this fermentation are considered toxic. On the other hand, the putrefaction of proteins gives rise to a number of end-products that are distinctly toxic. Under normal conditions and on a mixed diet, carbohydrate fermentation is the characteristic action of the organisms in the small intestine; while protein putrefaction occurs in the large intestine. The reason for this seems to be that carbohydrates serve to protect proteins because some of the organisms of the small intestine, *i.e.*, bacillus coli, will not attack proteins as long as carbohydrate material is present. In addition, the organic acids produced by the fermentation of carbohydrates tend to neutralize the alkalinity of the intestinal secretion, and may even give an acid reaction. An acid reaction is unfavorable to the action of the organisms that hydrolyze proteins, and in this way putrefaction in the small intestine is prevented. It seems that the nature of organismal activity in the small intes-

tine depends partly upon the character of the diet, which, therefore, may be intentionally chosen so as to favor one or the other kind.

The *bacillus acidophilus* is the species best adapted to maintaining good intestinal conditions. The taking of cultures of this organism and the liberal consumption of lactose, which is favorable to their development, often assist in establishing good intestinal hygiene.

Time required for digestion in small intestine. — This is difficult to state because many factors enter in. It depends largely on the varying proportions of the different foods included in a meal. According to observations made upon a patient with a fistula at the end of the small intestine, food begins to pass into the large intestine in from two to five hours after eating, and it requires nine hours or more after eating before the last of a meal has passed the colic valve.[19]

CHANGES THE FOOD UNDERGOES IN THE LARGE INTESTINE

Movements of the large intestine. — The opening from the small intestine into the large is controlled by the colic valve and the colic sphincter, which is normally in a state of tone. As food passes the colic valve, the cecum becomes filled, and gradually the accumulation reaches higher and higher levels in the ascending colon. The contents of the ascending colon are soft and semisolid, but in the distal end of the transverse colon they attain the consistency of feces.

A type of movement characteristic of the large intestine is called *haustral churning.* The little pouches, or sacculations, which are found in the large intestine, become distended, and from time to time contract and empty themselves. Another type of movement is designated as *mass peristalsis.* It consists of the vigorous contraction of the entire ascending colon, which transfers its contents to the transverse colon. Such movements occur only three or four times a day and last only a short time. Some observers connect them with eating, and assume that the entrance of food into the stomach sets up a reflex movement in the colon.

Secretion of the large intestine. — The secretion of the large intestine contains much mucin, shows an alkaline reaction, and does

[19] Twenty to thirty-six hours are required for the passage of ingested food material through the gastrointestinal tract of adults who are upon a mixed diet. There is considerable variation among individuals and usually not all of the residue from a single meal is evacuated at the same time. In diarrheal conditions the time is much shortened.

not contain enzymes. When the contents of the small intestine pass the colic valve, they still contain a certain amount of unabsorbed food material. This remains a long time in the intestine, and since it contains the digestive enzymes received in the duodenum, the process of digestion and absorption continues.

Action of organisms in large intestine. — Protein putrefaction due to the action of organisms is a constant and normal occurrence in the large intestine. The reaction is alkaline, and whatever protein may have escaped digestion and absorption may be acted upon by the organisms and undergo putrefactive fermentation. The splitting of the protein molecules by this process is very complete, not only are they broken down to their amino-acids, but the groups of which the amino-acids are formed are liberated. The list of end-products of putrefaction is a long one and includes not only peptones, proteoses, ammonia, and amino-acids, but also indol, skatol, phenol, fatty acids, carbon dioxide, hydrogen sulphide, etc. Some of the latter are given off in the feces, others are absorbed and carried to the liver, where they are changed to less toxic compounds, *e.g.*, ethereal sulphates, and ultimately excreted in the urine. Therefore the amount of these sulphates in the urine is indicative of the degree of intestinal putrefaction. Even though these sulphates and allied compounds are less toxic than those from which they are derived, they are more or less poisonous, and the feelings of malaise associated with constipation are thought to be due to the presence of these substances in the blood. Some investigators believe that bacterial putrefaction is harmful. A conservative view is that intestinal organisms are not beneficial, but under normal conditions the body is able to neutralize their effects.

The feces. — Two classes of material may be mingled in the contents of the colon, (1) the residues of the diet and (2) the excretions of the digestive tube and its glands. The proportion existing between these two is variable. The excretions are considered to be more prominent elements than the residues of the diet. The feces consist of (1) water, (2) the undigested and indigestible parts of the food, (3) the products of the secretions, (4) the products of bacterial decomposition, *i.e.*, indol, skatol, etc., (5) cholesterol, or a derivative, which is probably derived from the bile, (6) some of the purin bases, (7) mucus and epithelial cells from the walls of the intestine, (8) pigment due to undigested food, or to metallic elements contained in it and to the bile pigments, (9) inorganic salts of sodium, potassium, calcium, magnesium, and iron, (10) great quantities of microörganisms of different kinds.

Defecation. — The anal canal is guarded by an internal sphincter and an external sphincter muscle which are normally in a state of tonic contraction and protect the anal opening. Normally the rectum is empty until just before defecation. Various stimuli (depending on one's habits) will produce peristaltic action of the colon, so that a small quantity of feces enters the rectum. This irritates the sensory nerve-endings and causes a desire to defecate. The voluntary contraction of the abdominal muscles, the descent of the diaphragm, and powerful peristalsis of the colon all combine to empty the colon and rectum.

One of the commonest causes of constipation is the retention of feces in the rectum because of failure to act on the desire for defecation. After feces once enter the rectum there is no retroperistalsis to carry them back to the colon, and the sense of irritation becomes blunted. The desire may not recur for twenty-four hours, and during this time the feces continue to lose water, become harder, and more difficult to expel. The best means to prevent and overcome constipation are: (1) act upon the desire for defecation, and have a regular time for doing so; (2) use a liberal amount of fruit and vegetables. Some authorities teach that a certain amount of indigestible material in the diet is wholesome. It stimulates the lining of the intestines, promotes peristalsis, and as it is pushed along the tube takes with it the less bulky but more toxic wastes. (3) Form the habit of daily exercise of the abdominal muscles.

SUMMARY

- **Man's Dependence on Plants**
  - Life processes in plants are constructive
    - Cells of green plants contain chloroplasts — synthesize CO_2 and H_2O into carbohydrates.
    - Plant cells using carbohydrates as a basis make fats and with nitrates make proteins.
  - Life processes in man are first destructive, then constructive
    - Process of digestion splits carbohydrates, fats, and proteins of food into simple sugars, gylcerin and fatty acids, and amino-acids. The tissue cells can synthesize these standard substances into carbohydrates, fats, and proteins characteristic of their own tissues.
- **Food**
  - Any substance taken into the body
  - 1. To yield energy.
  - 2. To provide material for growth of tissues.
  - 3. To regulate body processes.
- **Classification**
  - Chemical analysis shows that elements found in body are found in food.
  - Nutrients or Food Principles
    - Water.
    - Carbohydrates.
    - Fats.
    - Proteins.
    - Ash constituents or mineral salts.
    - Vitamins.

Water

- Enters into composition of all tissues; most tissues contain from 75% to 90%.
- Greater proportion in young animals and active tissues.
- Constitutes about $\frac{2}{3}$ of daily income.
- Sources of water content of body
  - Water we drink.
  - Water contained in food
  - Water formed in the tissues.
- Supplies fluid for
  - Secretions.
  - Chemical reductions.
  - Transfer of food material.
  - Elimination of waste.
- Important in heat regulation.
- Under normal conditions amount in body remains about the same.

Carbohydrates

- Most abundant and most economical source of energy. Consist of C, H, and O, the two latter in the proportion to form water. Include sugars and starches.
- Monosaccharides
  - Contain one sugar group.
  - Glucose or dextrose $C_6H_{12}O_6$ } Invert sugar.
  - Fructose or levulose $C_6H_{12}O_6$ } Invert sugar.
- Disaccharides
  - Contain two sugar groups.
  - Sucrose or cane-sugar $C_{12}H_{22}O_{11}$.
  - Lactose or milk-sugar $C_{12}H_{22}O_{11}$.
  - Maltose or malt-sugar $C_{12}H_{22}O_{11}$.
- Polysaccharides
  - Contains many sugar groups.
  - Starch $(C_6H_{10}O_5)n$.
  - Cellulose $(C_6H_{10}O_5)n$.
  - Glycogen $(C_6H_{10}O_5)n$.
  - Dextrin $(C_6H_{10}O_5)n$.

Fats

- Used in anatomic sense = adipose tissue.
- Used in chemical sense = compound of C, H, and O, but the C and H content is relatively high.
- Made from one molecule of glycerin and three molecules of fatty acid. Reaction comparable to neutralization of an acid by a base.

  Stearic acid + Glycerin → Stearin + Water

  $$3\,H \cdot C_{18}H_{35}O_2 + C_3H_5(OH)_3 \rightarrow C_3H_5(C_{18}H_{35}O_2)_3 + 3\,H_2O$$
- Under influence of body enzymes, split into substances out of which they are built. Reaction reverse of above.

  Stearin + Water → Glycerin + Stearic acid

  $$C_3H_5(C_{18}H_{35}O_2)_3 + 3\,H_2O \rightarrow C_3H_5(OH)_3 + 3\,H \cdot C_{18}H_{35}O_2$$

Compound Fats

- Esters of fatty acids containing groups in addition to a base and a fatty acid.
- *Phospholipides* — contain phosphorus and nitrogen, *e.g.*, lecithin.
- *Glycolipides* — compounds of fatty acids with a carbohydrate — *e.g.*, cerebrosides.
- *Sterols* — solid alcohols combined with fatty acids — *e.g.*, cholesterol.

Proteins

- Contain C, H, O, N; usually S, sometimes P and Fe may be present.
- Differ from carbohydrates and fats in having nitrogen, hence called nitrogenous.
- Built up of simpler substances called amino-acids.
- Amino-acids contain an amino radical (NH_2) instead of a replaceable hydrogen.
- Acetic acid — CH_3COOH — for replaceable H substitute (NH_2) $\rightarrow$ $CH_2(NH_2)COOH$ = Amino-acetic acid.
- Propionic acid — C_2H_5COOH — for replaceable H substitute (NH_2) $\rightarrow$ $C_2H_4(NH_2)COOH$ = Amino-propionic acid.
- About eighteen amino-acids have been described, and various combinations result in many different kinds of proteins, *i.e.*, milk, meats, fish, egg, peas, beans, lentils, and peanuts.
- **Examples of protein constituents of food**
  - Albumin — found in egg, milk, meat.
  - Caseinogen — found in milk.
  - Gluten — gummy substance in wheat.
  - Legumin — found in legumes.
  - Gelatin — derived from connective tissues including bone and tendon.
  - Organic extracts — flavor of meats and some plant foods due to these.
- **Classification**
  - Simple
    - Consists only of amino-acids.
    - Yield only amino-acids or derivatives.
  - Conjugated
    - Contain protein molecule united to some other molecule otherwise than as a salt — yield amino-acids and some other molecule.
    - Nucleoproteins — yield amino-acids and nuclein.
    - Glycoproteins — yield amino-acids and a carbohydrate.
    - Phosphoproteins — yield amino-acids and a phospho body.
    - Hemoglobins — yield amino-acids and hematin.
    - Lecithoproteins — yield amino-acids and a fatty substance.
  - Derived
    - Primary — involve only slight alterations of the protein molecule.
    - Secondary — products of further hydolytic cleavage.

Chemical Elements

- Fifteen or more elements enter into composition of the body.
- Five may be furnished by carbohydrates, fats, proteins, and water.
- Ten others to be provided are:
  Iron, Calcium, Sodium, Potassium, Magnesium, Phosphorus, Chlorine, Iodine, Fluorine, Silicon.
- **Function**
  - As constituents of bone.
  - As essential elements of soft tissues.
  - As soluble salts held in solution in fluids of body.

Vitamins

- Essential for growth and maintenance.
- Influence the metabolism of all the foodstuffs.
- Chemical composition unknown, thought that they act as hormones.
- **Vitamin A or Fat-soluble A**
  - Stands for a substance or group of substances which are essential to growth and health.
  - A, D, and E are fat-soluble vitamins.
  - Lack of this vitamin results in
    (1) cessation of growth,
    (2) more or less susceptibility to xerophthalmia and
    (3) widespread weakening of body tissues.
  - Occurs in milk, butter, egg yolk, green leaves of plants, cod-liver oil, liver, kidneys, and sweetbreads.
- **Vitamin B**
  - Thought to consist of two or more fractions, propose to call vitamin B and G.
  - Vitamin B Anti-neuritic
    - Essential to normal growth.
    - Stimulates appetite.
    - Absence or deficiency results in beri-beri or polyneuritis.
  - Vitamin G Anti-pellagric
    - Essential to normal growth.
    - Absence or deficiency one factor in producing pellagra.
  - Occurs in seeds of plants, eggs of animals, milk, yeast, green vegetables such as spinach, leaves of turnips or beets, radishes, watercress, lettuce, and the germ of cereals.
- **Vitamin C Anti-scorbutic**
  1. Lack of this vitamin results in symptoms of scurvy.
  2. Occurs in fruits, oranges, lemons, tomatoes, and leafy parts of plants.
  3. Least resistant to drying and heating unless done in presence of acids, or absence of oxygen.
- **Vitamin D Antirachitic**
  - Found in cod-liver oil and egg yolk.
  - Specific for rickets.
- **Vitamin E sterility**
  - Sterility of rats may be produced by a synthetic diet which contains vitamins A and B, and is adequate for growth.
  - Sterility can be overcome by adding lettuce, meat, liver, or egg-yolk to diet.

Accessory Articles of Diet

- Flavors and condiments: The various oils and esters that give odor and taste to food. Salt, pepper, mustard, etc.
- Stimulants: Tea, coffee, cocoa, meat extracts, alcohol, etc.

Digestive Processes

- Various physical processes that are preliminary to the more important chemical digestion.
- **Mechanical**
  - Mastication.
  - Deglutition or swallowing.
  - Peristaltic action of esophagus.
  - Movements of stomach.
  - Movements of intestines.
  - Defecation.
- **Chemical**
  - Splitting of complex substances into simpler ones.
  - Process of hydrolysis that is dependent on enzymes.
  - Rendered necessary by variety and complexity of foods, which must be reduced to standard and simple substances that the tissues can use, *i.e.*,
  - Simple sugars.
  - Glycerin and fatty acids.
  - Amino-acids.

Enzymes

- Substances produced by living cells which act by catalysis, *i.e.*, vary, hasten, or retard speed of reactions.
- It is suggested that each hydrolytic enzyme be designated by the name of the substance on which it acts, together with the suffix, *ase*.
- **Classification according to action**
  1. Sugar-splitting
     - *a.* Inverting.
     - *b.* Enzymes which act on simple sugars.
  2. Amylolytic or starch-splitting.
  3. Lipolytic or fat-splitting.
  4. Proteolytic or protein-splitting.
  5. Clotting enzymes.
  6. Oxidizing enzymes, or oxidases.
  7. Deaminizing enzymes.

LIST OF DIGESTIVE FLUIDS AND CHIEF ENZYMES

Digestive Fluids	Enzymes	Functions
Saliva	Ptyalin or salivary diastase	Hydrolyzes starch to dextrin and sugar (maltose).
	Maltase	Aids the change of maltose to glucose.
Gastric	Pepsin plus hydrochloric acid	Hydrolyzes proteins into proteoses and peptones.
	Rennin	Curdles the caseinogen of milk.
	Gastric lipase	May initiate the digestion of emulsified fats such as cream.
Pancreatic	Trypsin, trypsinkinase, and erepsin	In a slightly acid, neutral, or strongly alkaline medium, these enzymes act at different stages of protein decomposition and reduce proteins to amino-acids.

Digestive Fluids	Enzymes	Functions
Pancreatic	Amylase or Diastase	Hydrolyzes starch to dextrin and sugar (maltose).
	Lipase or Steapsin	Splits fats to glycerin and fatty acids. This action is reversible. Activates union of fatty acids with alkalies — saponification.
Succus Entericus	Enterokinase	Activates the trypsin of the pancreatic fluid, or acts as a co-enzyme.
	Erepsin	Hydrolyzes peptids to amino-acids.
	Inverting — Maltase	Hydrolyzes dextrin amd maltose to dextrose.
	Inverting — Invertase	Hydrolyzes sucrose to dextrose and levulose.
	Inverting — Lactase	Hydrolyzes lactose to dextrose and galactose.
	Nuclease	Acts upon the nucleic acid of nucleo-proteins.
Bile	No enzyme	Serves as coenzyme and activates the lipase of the pancreatic fluid.

Changes food undergoes in mouth

- Mastication (chewing).
- Insalivation (mixing with saliva).
- Saliva
  - Secreted by salivary glands — Parotid, Submaxillary, Sublingual — and mucous glands of mouth.
  - Craniosacral autonomic fibers
    - Carry secretory and vasodilator fibers.
    - Stimulated by sight or smell of food.
    - Produce a copious amount of watery secretion.
  - Thoracolumbar autonomic fibers
    - Carry secretory and vasoconstrictor fibers.
    - Stimulated by food in mouth.
    - Produce a smaller amount of thicker secretion.
  - Consists of water, some protein material, mucin, inorganic salts, and enzymes — **ptyalin** and **maltase.**
  - Specific gravity 1.004–1.008. Neutral in reaction — pH 6.6 to 7.1.
  - **Functions**
    1. Assists in mastication and deglutition.
    2. Serves as a lubricant.
    3. Dissolves or liquefies the food, thus stimulating the taste buds, and indirectly the secretion of gastric fluid.
    4. Ptyalin hydrolyzes starch to dextrin and maltose; maltase changes maltose to glucose.
- **Deglutition** (swallowing). Passage of food through (1) fauces, (2) pharynx, and (3) esophagus. Consistency of food affects third stage.

Stomach Digestion

- Definition — changes the food undergoes in the stomach.
- Time required — depends on nature of food eaten, average meal of mixed food requires from five to seven hours.
- Food held in stomach by contraction of cardiac and pyloric sphincters.
- Cavity size of contents — never empty — always few cc. of gastric fluid in stomach.
- When food enters — expands just enough to receive it — contractions start in middle region and run toward pylorus — food in prepyloric and pyloric regions macerated, mixed with gastric fluid, and reduced to **chyme.**
- Salivary digestion continues until gastric fluid penetrates bolus of food.
- **Dependent on Gastric Fluid**
  - Secretion
    - Periods of fasting — secreted in small amount.
    - While eating and during period of digestion — amount increased.
    - Psychical or appetite secretion
      - Sensations of eating.
      - Taste and odor of food.
    - Chemical
      - Secretagogues contained (1) in food and (2) in products of digestion.
      - Gastric secretin.
  - Secreted by glands of stomach
    - Cardiac.
    - Fundus or oxyntic.
    - Pyloric.
  - Acid reaction due to free hydrochloric acid.
  - Enzymes
    - Pepsin.
    - Rennin.
    - Gastric lipase.
  - Inhibited by
    - Stimulation of sympathetic system, anger, pain, fear, worry, distaste for food.
    - Secretion dependent on blood, hence checked if blood-supply is diverted.

Hydrochloric Acid

- Secreted by patietal cells of gastric glands from chlorides found in blood.
- NaCl most abundant — chlorine combines with hydrogen to form hydrochloric acid.
- Normal proportion about 0.2 per cent.
- **Functions**
  - Activates pepsinogen and converts it to pepsin.
  - Provides acid medium for pepsin to carry on its work.
  - Swells protein fibers.
  - Helps in inversion of cane-sugar, easiest disaccharide to invert.
  - Acts as a disinfectant and may kill bacteria.
  - Helps to regulate opening and closing of pyloric valve.

Pepsin
- Formed in pyloric glands and chief cells of gastric glands.
- Pepsinogen — zymogen, changed by HCl to active pepsin.
- Weak proteolytic enzyme — requires acid medium.
- Hydrolyzes proteins through several stages to proteoses and peptones, which action is preparatory to more complete hydrolysis in intestine.

Rennin
- Formed in chief cells of gastric glands.
- Prorennin — zymogen — secretin converts to active enzyme.
- Acts only upon casein, converts it to paracasein, which reacts with calcium to form the curd, preparatory to further action by pepsin and trypsin.

Gastric Lipase — Limited action on emulsified fats like cream.

Functions of Stomach
- Serves as temporary storage reservoir.
- Contractions promote mechanical reduction of food.
- Salivary digestion continues until acidity is established.
- Gastric digestion
  - Pepsin hydrolyzes proteins.
  - Rennin hydrolyzes caseinogen.
  - Gastric lipase may hydrolyze emulsified fats.
- HCl has germicidal action — hence stomach serves as disinfecting station.

Intestinal Digestion
- Definition — changes the food undergoes in the small and large intestine.
- **Small Intestine**
  - **Movements**
    - Peristaltic — pushes food forward slowly.
    - Rhythmical — breaks food up into small particles, facilitates mixing with intestinal secretions.
  - **Secretions**
    - Pancreatic fluid.
    - Succus entericus.
    - Bile.
  - **Bacteria**
    - Decompose carbohydrates.
    - Little or no effect on protein.
  - **Time required**
    - Depends on proportions of different foodstuffs.
    - Food begins to pass into large intestine from 2 to $5\frac{1}{4}$ hours after eating, requires 9 or more hours before last of meal has passed.
- **Large Intestine**
  - **Movements**
    1. Antiperistalsis — press mass backward toward colic valve.
    2. Haustral churning.
    3. Mass peristalsis moves food from one division to another.
  - Secretion — contains mucin — no enzymes, alkaline reaction.
  - Digestive enzymes from duodenum continue to act.
  - **Bacteria**
    - Hydrolysis of proteins constant.
    - Possible action on cellulose.
    - Benefit doubtful.

Pancreatic Fluid

- Secretion controlled by hormone secretin. Discharged into small intestine during digestion.
- Clear, viscid fluid, alkaline reaction.
- **Secretion**
  - Nervous secretion caused by secretory fibers in vagus and splanchnic. It is thick, rich in enzymes.
  - Chemical secretion due to secretin. It is thin, watery, poor in enzymes, alkaline.
- **Enzymes**
  - Proteolytic
    - Formerly thought one enzyme, trypsin reduced protein to amino-acids. Now thought that *trypsin, trypsin-kinase,* and *erepsin* are necessary and act at different stages.
  - Amylolytic or Amylase
    - Action similar to ptyalin.
    - Hydrolyzes starch to achroödextrin and maltose.
  - Lipolytic or Lipase
    - Hydrolyzes fats to glycerin and fatty acids.
    - Emulsification depending on saponification occurs as soon as small amount of fat is split to fatty acids and gylcerin.
    - Fatty acid combines with alkaline salts to form soaps. Hence emulsification regarded as preparatory process.
    - Action is reversible — synthesizes fatty acids and glycerin to form fat, characteristic of human animal.

Succus Entericus

- Secretion thought to be promoted by secretin.
- Clear yellowish fluid, alkaline reaction due to sodium carbonate.
- **Enzymes**
  - Enterokinase — acts as co-enzyme.
  - Erepsin — hydrolyzes peptids to amino-acids.
  - Maltase — hydrolyzes dextrin and maltose to dextrose.
  - Invertase — hydrolyzes sucrose to dextrose and levulose.
  - Lactase — hydrolyzes lactose to dextrose and galactose.
  - Nuclease — acts upon nucleic-acid portion of nucleo-proteins.
- **Secretin**
  - Two views are held.
  - 1. Secretin exists in form of prosecretin and is changed by acid of gastric fluid to secretin.
  - 2. Secretin is performed in duodenum and is liberated by the bile.

Bile
- Alkaline liquid, color may be yellow, brownish-yellow, or olive green.
- Amount secreted varies with amount of food eaten, estimated about 500 to 800 cc. daily.
- Consists of water, bile pigments, bile acids, bile salts, cholesterol lecithin, neutral fats, soaps, and nucleo-albumin.
- Bile-salts, *i.e.*, sodium taurocholate and sodium glycocholate, thought to stimulate activity of the liver.
- Secreted continuously, enters duodenum during period of digestion.
- Digestive secretion aids the action of lipase.
- Excretion — Eliminates toxins, metals, and cholesterol.
- Antiseptic — thought to limit putrefaction.

Abnormal conditions
- Gall-stone — concentrated cholesterol which crystallizes out and forms gall-stones.
- Jaundice — due to absorption of bile by blood — carried throughout body — pigments deposited in skin and whites of eyes.

Feces
- **Consist of**
  - Residues of diet.
  - Excretions of digestive tube and its glands.
- Contains (1) water, (2) the residues of food, (3) products of secretions, (4) products of bacterial decomposition, indol, skatol, etc., (5) cholesterol, (6) purin bases, (7) mucous and epithelial cells, (8) pigment, (9) inorganic salts, and (10) microörganisms.

Defecation — term applied to the act of expelling feces from rectum.

CHAPTER XX

ABSORPTION OF FOOD FROM THE ALIMENTARY CANAL. METABOLISM OF CARBOHYDRATES, FATS, AND PROTEINS

By absorption is meant the passage of digested food material from the cavity of the alimentary canal to the blood. Though food may be digested and ready for nutritive purposes, it is practically outside of the body until it passes through the walls of the alimentary canal.

Conditions which determine the amount of absorption which takes place from any part of the alimentary canal may be listed as follows:

1. Character of the epithelial cells.
2. Area of surface for absorption.
3. Length of time during which food remains in contact with an absorbing surface.
4. Concentration of fully digested material present.

Absorption in the small intestine. — It is in the small intestine that these conditions are most favorable for absorption, and it is in the small intestine that the greatest amount of absorption takes place.

1. Absorption in the small intestine takes place more readily and completely than can be explained by the physical laws of diffusion and osmosis. On this account the living epithelial cells are credited with absorptive activities which are not entirely understood and which are usually described as *selective action.*

2. The circular folds and villi of the small intestine increase the internal surface to such an extent that some authorities state that the actual absorbing surface is about ten square meters.

3. Food remains in the small intestine for several hours, during which time the most complete digestive changes occur.

4. The blood flows steadily within a cellular wall composed of the coats of the blood-vessels and the intestinal mucosa. On the intestinal side of the wall are the products of digestion and the digestive fluids. Sugars, glycerin, fatty acids, and amino-acids are relatively abundant and diffuse into the blood, which contains little of these substances. The continuous digestion of foods,

the muscular activity of the intestinal wall, and the lashing and pumping activities of the villi stir up the intestinal contents and keep relatively high the concentration of absorbable materials in contact with the absorbing membrane. These motions also increase the circulation in the villi, and therefore the absorbed materials do not accumulate, raising the concentration in the blood. Absorption takes place through the membrane from a constantly higher concentration to a constantly lower concentration until all digested material is absorbed.

Paths of absorption. — The two paths by which the products of digestion find their way to the blood are the lacteals and the capillaries of the villi.

Fats are absorbed into the central lymph channel of each villus and forced into the larger lymphatics. After reaching the large lymph-vessels, the absorbed material flows to the thoracic duct and enters the innominate vein at the junction of the left internal jugular and left subclavian.

The products of carbohydrate and protein digestion and probably some of the glycerin and fatty acids are absorbed by the capillaries of the villi and carried to the portal tube, which in turn carries them to the liver.

Absorption in the stomach. — Absorption does not take place readily in the stomach. Alcohol and alcoholic solutions are absorbed. Small amounts of sugar, amino-acids, and other organic substances may be absorbed. Water is not absorbed. This is true even when large amounts of fluid have been lost from the body, and extreme thirst is present. When there is stricture or paralysis of the pylorus, or lack of tone of the muscular walls of the stomach (as often happens after an individual has been kept under a general anæsthetic for some time), the introduction of water into the stomach causes distention, often followed by vomiting. Condiments such as mustard, pepper, etc., are said to increase the permeability of the mucous membrane.

Absorption in the large intestine. — When the contents of the small intestine pass the colic valve, they still contain a certain amount of unabsorbed food material, and due to the contained enzymes digestion and absorption continue. The consistency is about that of chyme. This is possible because the absorption of water from the small intestine is made good by diffusion or secretion of water into it. In the large intestine the absorption of water is marked, sufficiently so under usual conditions to cause the formation of semi-solid or hard feces.

Water. — Water is not appreciably absorbed in the stomach. Large quantities are absorbed in the small intestine, but it is in the large intestine that the most marked absorption takes place.

Mineral salts. — The absorption of salts from any part of the intestines depends upon (1) the nature of the salt and (2) the concentration of the solution. Certain salts are readily absorbed, *e.g.*, acetates, chlorides, and most of the ammonium salts; on the other hand, tartrates, citrates, and some of the sulphates are not absorbed. For the absorbable salts to be absorbed, they must be in higher concentration in the intestine than in the blood.

Cathartic action of salts in solution in water. The cathartic salts — tartrates, citrates, sulphates — are salts in solution in water and the salts are not absorbable. Their cathartic action is due to their effect on the movement of water through the intestinal wall. Hypertonic solutions of the salts will draw water from the blood into the intestinal cavity, increasing the bulk of the intestinal contents, thereby acting as cathartics.

End-products of digestion. — The products resulting from digestion are: (1) simple sugars, derived from the various carbohydrates, (2) fatty acids and glycerin, derived from the various fats, and (3) amino-acids, derived from the various proteins.

These substances are more diffusible than the foodstuffs from which they are derived. Starch, even when boiled for a long time, does not make its way through ordinary membranes; the simple sugars do. Fats are not diffusible in water, fatty acids and glycerin are diffusible. Amino-acids pass freely through membranes.

(1) The simple sugars pass into the capillaries and thence by way of the portal tube to the liver.

(2) The fatty acids and glycerin are absorbed as such in the small intestine. The bile furnishes bile salts (sodium glycocholate and sodium taurocholate), which aid in the absorption of the split fats. During their passage through the intestinal walls the fatty acids and glycerin recombine to form simple fats. It is believed that this synthesis is due to the action of lipase. The greater part of the fat is absorbed by the lacteals in the villi and carried to the thoracic duct which empties into the left innominate vein. In addition it is considered probable that some of the fat is absorbed as fatty acid and glycerin directly by the capillaries of the villi, and carried by way of the portal tube to the liver, before reaching the general circulation.

(3) The amino-acids pass into the capillaries of the villi, although there is experimental evidence that, after excessive feeding of protein, a portion may enter the lymphatics. Amino-acids are found in the blood, which distributes them to the tissues.

METABOLISM

General metabolism includes all the processes involved from the time food enters the body until it is excreted. Ordinarily the use of the term is limited to include only the changes that occur in digested foodstuffs from the time of their absorption until their elimination in the excretions. This includes all the chemical activities that take place within cells. It is in this latter way that it is used in this chapter.

Metabolic changes. — The changes constituting metabolism can be classified under two heads: (1) **anabolism,** or constructive processes, and (2) **catabolism,** or destructive processes.

(1) The changes classified as anabolic or anabolism include the processes by which cells take food substances from the blood, and make them a part of their own protoplasm. This involves the conversion of non-living material into living material and is a building up or synthetic process. The synthesis of glycogen and of fats within the cells is also anabolism. Comparatively little is known of the nature of anabolic changes, but it is thought they are largely of the dehydration type, which is the opposite of hydrolysis. Dehydration consists of the putting together of molecules with a loss of water.

(2) The changes classified as catabolic or catabolism consist of the processes by which cells resolve into simpler substances: (*a*) part of their own protoplasm, or (*b*) substances which have been stored in them. This disintegration yields simpler substances, some of which may be used by other cells, though most of them are excreted. The catabolic processes consist mainly of (1) the simple splitting of complex molecules into smaller ones; (2) hydrolysis, *i.e.*, the splitting of complex molecules into simpler ones with the absorption of water, and (3) oxidation[1] or the union of oxygen with the constituents of the cells. When oxygen reaches the tissues, its participation in the chemical changes of the body forms an integral part of the processes of nutrition.

Functions of metabolism. — Metabolic changes serve the following purposes: (1) the growth and repair of tissue, and (2) the release of energy in the form of heat, nervous activity, muscular activity, etc.

Factors which promote metabolic changes. — Factors which promote metabolic changes are: (1) oxygen absorbed from the

[1] The addition of oxygen to a substance or the withdrawal of hydrogen from it. Oxidation and reduction both occur at the same time. An oxidation of one substance means reduction of something else.

lungs, (2) enzymes formed by the tissue cells, (3) hormones formed by the ductless glands, (4) vitamins furnished by food, and (5) the nervous system. For the sake of simplicity in description, the metabolism of each of the foodstuffs will be considered separately.

METABOLISM OF CARBOHYDRATES

It is convenient to consider the history of carbohydrates under three heads: (1) supply; (2) storage; and (3) consumption.

(1) The supply is regulated by the diet.

(2) The storage is provided for temporarily by the liver, the muscles, and the cells of the tissues.

During the process of digestion all the carbohydrates are changed to simple sugars. Absorption of glucose takes place mainly into the capillaries of the small intestine. These capillaries pour their contents into the portal tube, which carries the blood rich with glucose to the liver. The liver cells take this glucose from the blood, and by putting together a number of molecules and withdrawing water the soluble glucose is changed to insoluble glycogen, which is stored in the liver cells. In thus storing up glycogen and doling it out as needed, the liver helps to maintain the normal quantity of glucose — 0.09 to 0.12 per cent — in the blood. From the blood-stream glucose is taken up by the muscles and other tissues and stored as glycogen until needed. Hence the liver serves as a central storehouse from which the tissues receive their supply whenever their content of glycogen is depleted. The percentage of glycogen in a muscle cell is small, though the total content of all the muscle cells may equal that of the liver. The maximum storage of glycogen in the body is about 400 gm. or nearly one pound. The conversion of glycogen into glucose as it is required by the tissues is thought to be effected by glycogenase, an enzyme contained in the liver cells. The need of the blood for glucose is constant, because it is constantly giving up glucose to the tissues.

(3) At the consumption end the amount of sugar oxidized is controlled by the energy needs of the tissues, particularly the muscles, for their activity is the principal factor determining the rate of oxidation, and naturally the amount of fuel required will be in proportion to the rate at which it is used.

Regulation of blood sugar. — The regulation of the amount of sugar in the blood is important. Several processes are concerned: (1) the production of glycogen in the liver (glycogenesis), (2) the conversion of glycogen to sugar according to body needs (glycogen-

olysis), (3) the consumption of sugar in the tissues (glycolysis), and (4) the possible loss of sugar through the kidneys (glycosuria).

These processes must be regulated and adapted one to another. Just how this regulation is effected is not known.

Insulin. — Insulin, the hormone of the pancreas, is essential for the normal course of sugar metabolism. In derangements of carbohydrate metabolism insulin restores the power to utilize the glucose of the blood, accelerates the synthesis of sugar to glycogen, and the storage of glycogen in the liver and muscles. It restricts the production of sugar in the liver from protein and fat, a process which probably occurs under normal conditions, but is greatly increased in diabetes. It also counteracts the tendency to acidosis.

Insulin is ineffective when taken by mouth, because it is decomposed in the alimentary canal; consequently, it is injected under the skin. The reduction of blood sugar by insulin does not necessarily stop at the normal level; if it proceeds farther, prostration may occur. Such reaction is avoided by eating oranges or chocolate, when the sensation of weakness is first felt. The improvement of patients receiving insulin is marked, but insulin does not cure diabetes. It is palliative in character and dependence on the injections must continue. Diabetes affects chiefly individuals who have allowed themselves to become overweight. In later life, the person who is of normal or less weight is practically insured against diabetes.

It may be there is a *sugar-regulating center* in the medulla, which controls the conversion of glycogen to sugar; some think that control is exercised indirectly through the *adrenal glands.* An increase of sugar concentration in the blood is followed by elimination of sugar in the urine (glycosuria). An instance of such glycosuria is that following strong emotion. One result of emotional excitement is an increased secretion of epinephrin into the blood, and one of the effects of epinephrin is to convert a large amount of glycogen to glucose. It is thought that this release of sugar may be a provision to supply fuel to the muscles under conditions which usually call for strenuous action.

Functions of carbohydrates. — The oxidation of glucose serves the following purposes: (1) It furnishes the main source of energy for muscular work and for all the nutritive processes of the body. The glycogen of a muscle disappears in proportion to the work done by the muscle, and it is thought the oxidation of the sugar furnishes the energy which is utilized by the muscles. (2) It furnishes an important part of the heat needed to maintain the body temperature. The oxidation of each gram of sugar yields four Calories of heat, and since the carbohydrates form the largest part of our diet, and are easily oxidized, they must

be regarded as specially available material for keeping up body heat. (3) It prevents oxidation of the body tissues, because it constitutes a reserve fund that is the first to be drawn upon in time of need. As carbohydrate food is increased, protein food may be diminished down to a certain irreducible minimum, which is probably the amount necessary for the reconstruction of new tissue. (4) An excess of carbohydrates over and above what can be stored as glycogen in the liver and muscles is converted into adipose tissue. Nutritional experiments leave no doubt that the fat of the body may be formed from carbohydrate food. (5) Man is unable to oxidize fatty acids completely, unless there is an accompanying oxidation of glucose.

Waste products of carbohydrate metabolism. — Eventually the glucose derived from the glucose of the blood or from the glycogen of the cell is oxidized by the cell to *carbon dioxide* and *water.*

Derangements of carbohydrate metabolism. — The sugar-regulating mechanism of the body may prove inadequate.

(1) The mechanism of conversion of sugar to glycogen in the liver (glycogenesis) breaks down, giving rise to alimentary glycosuria, *i.e.*, sugar in the urine. This may follow the ingestion of a larger amount of sugar than the liver and muscles can store, resulting in an increased amount in the blood (hyperglycemia). A higher percentage of sugar than normal (0.08 to 0.18 per cent) in the blood is irritating to the tissues, and the sugar is excreted in the urine. This is designated as temporary glycosuria.

(2) The mechanism of conversion of glycogen to sugar in the liver (glycogenolysis) breaks down in injuries to the central nervous system, excessive internal secretion by the suprarenal glands, etc.

(3) The mechanism of consumption of sugar in the tissues for energy purposes (glycolysis) breaks down in diabetes mellitus. Removal of the pancreas of an animal is followed by the appearance of sugar in the urine in large amounts. If the extirpation is complete, glycosuria is followed by emaciation and muscular weakness, which finally end in death in two or three weeks. On the other hand, if a portion of the pancreas is left, even though its connection with the duodenum is interrupted, it may prevent glycosuria partly or completely. This indicates that the internal secretion is the important factor in the metabolism of sugar.

(4) The normal impermeability of the kidney breaks down in phlorizin diabetes. Phlorizin is obtained from the roots of certain trees, such as apple and pear. When injected into an animal, it causes a temporary glycosuria, which is very complete as long as the action of the drug lasts. Examination of the blood reveals the fact that the percentage of sugar is not increased, so that the immediate cause of the glycosuria is different from that responsible for diabetes of man or of animals without the pancreas. It is thought that phlorizin acts on the kidney itself.

Diabetes mellitus. — In mankind derangements of carbohydrate metabolism manifest themselves chiefly in the disease known as diabetes mellitus, the early symptoms of which are excessive secretion of urine containing abnormal amounts of glucose and urea, and abnormal thirst and hunger. In this disease the daily loss of sugar in the urine may be very large. In severe cases all the carbohydrate of the food may be excreted in the form

of sugar, and even when no carbohydrate food is eaten, sugar continues to be excreted in considerable amounts. In the latter case the sugar is supposed to have its source in the proteins of the food or of the tissues. The opinion of experts in this field is that a lesion in the islands of Langerhans in the pancreas results in a reduction of the supply of insulin to the body and in consequence the tissues cannot use the sugar brought to them by the blood. In addition to the sugar found in the urine in diabetes, this secretion may contain considerable amounts of the acetone bodies. These acetone bodies are intermediary products in the metabolism of fats, and their presence is due to incompleteness in the normal processes of the oxidation of fat. The accumulation of acetone bodies in the blood and tissues of the diabetic is responsible for the condition called *acidosis*.

METABOLISM OF FATS

The results of experimental work confirm the view that, after fat is split into glycerin and fatty acids by the lipase of the pancreatic fluid, it is absorbed by the epithelial cells and, in the very act of passing through them, combines to form fat. This combination is brought about by lipase. The greater portion of the fat passes into the central lymph channel of each villus. From these small lacteals it finds its way through the larger lymphatics in the mesentery to the thoracic duct, and then through the thoracic duct to the blood. It seems probable that some of the fat is absorbed by the villi, enters the portal tube, and passes through the liver before reaching the general circulation. Fat is carried by the blood to all parts of the body, and the tissues slowly take it out as they need it in their metabolic processes. Within the tissues it serves as fuel and is oxidized to supply the energy needs of the cells.

Functions of fat. — The fat absorbed as food may serve several purposes. (1) It may be oxidized with the liberation of energy. From a chemical standpoint, fats contain more available energy, weight for weight, than the proteins or the carbohydrates. (2) If fat is eaten and absorbed in excess of the actual needs of the body, the excess is stored in adipose tissue, and represents reserve nourishment to be drawn upon in time of need. (3) Fat may be synthesized with other substances and form compound fats, such as lecithin. The fat of the active tissues of the body, as distinguished from deposits of fat called adipose tissue, consists largely of compound fats and fat-like substances. (4) The glyceryl radical of fat may be converted to glucose.

Oxidation of fat in body. — It is thought that the first step in the splitting of fat is brought about by the lipase found in the tissues. The fat stored in adipose tissue in various parts of the body, *e.g.*, under the skin, peritoneum, etc., does not undergo oxidation in

these places. In time of need it is absorbed and distributed to the more active tissues. It is thought that lipase controls the output of fat to the blood, just as the liver enzymes control the supply of sugar in the blood. After the action of the lipase, oxidation takes place in a series of steps which reduces the higher fatty acids to simpler ones, and these in turn are oxidized to carbon dioxide and water.

Origin of body fat. — The modern view is that the fat of the body is formed from the fats, carbohydrates, and proteins of the food. Proteins are usually a small part of the daily diet, and it is thought that body fat is formed from fat and carbohydrate foodstuffs first. If the amino-acids resulting from the digestion of protein food are not built into body protein, they are deaminized, and the organic acid radical left may be converted to sugar, glycogen, and fat.

Derangements of fat metabolism. — When fats are completely oxidized, the waste products are carbon dioxide and water. It is thought that such complete oxidation cannot occur unless sugar is being oxidized at the same time; hence the saying, "Fats burn in the flame of carbohydrates." When carbohydrate is removed from the diet, and the glycogen of the body has been depleted, during fasting or under-feeding, and in severe diabetes, the body lives on its fats and proteins. Under these conditions the oxidation of fats is incomplete, and acetone bodies are found in the urine. Their presence indicates acidosis, which may lead to coma and death.

Because of their tendency to form acetone bodies under certain conditions, fatty acids are said to have ketogenic properties. Certain amino-acids and the proteins of which they are constituents are also ketogenic. On the other hand, carbohydrates, the sugar-forming amino-acids, and glycerol are antiketogenic.

Obesity. — It is said that there are two kinds of obesity. One kind is caused by eating more food than the body needs, lack of exercise, or both. A diet that is rather bulky, but not highly nutritious, including fruit and the coarser vegetables, is recommended for this type of obesity. The second kind is associated with endocrine disturbances. Castration, the menopause, disease of the hypophysis, myxedema, and other physiological and pathological disturbances are usually, though not always, accompanied by deposits of abnormal amounts of fat.

METABOLISM OF PROTEINS

As a result of digestion, proteins are hydrolyzed to amino-acids, which are absorbed by the blood capillaries of the villi, pass into the portal tube, and are carried through the liver into the blood of the general circulation, and distributed to the tissues. The tissues select and store certain of these bodies, and in each organ subsequent use is made of them, either to build up new tissue or repair the wastes of metabolism. Thus amino-acids constitute the form in which protein food is presented to the tissues, just as glucose con-

stitutes the form in which carbohydrate food is presented. Amino-acids not used in building up protoplasm are broken down or deaminized in all of the tissues. The deaminization of amino-acids means that the amino radicals (NH_2) are removed. This nitrogenous portion is split off as ammonia and is converted to urea.[2]

The non-nitrogenous portion which is left after deaminization (organic acid radical) is oxidized to furnish energy, or is built up into glycogen and fat and is oxidized later. Therefore, this portion of the amino-acid may be regarded as a source of energy equivalent to that furnished by the carbohydrates and fats. According to this, it is obvious that some of the amino-acids are selected to construct tissue protein, and the balance not needed for this purpose serves to supply energy.

The blood contains amino-acids at all times; fasting does not free the tissues from them, neither does a high protein diet result in any great increase in the blood or tissues. Amino-acids are considered intermediary products in the building up and breaking down of body protein. Both the building up and breaking down are thought to occur in all the tissues.

Endogenous and exogenous metabolism. — Endogenous metabolism is the metabolism of the proteins of the tissues of the body. There is daily and rather uniform disintegration of the tissues, which represents a loss that must be made up. The amount of protein needed for this purpose is the amount necessary to rebuild that which is broken down. There is no way of storing reserve protein in the body comparable to the way in which fat is stored as adipose tissue, or carbohydrates as glycogen.[3] Consequently, in time of need, *i.e.*, when the supply of food is inadequate, there is no reserve supply of protein to be drawn upon, and the proteins of the tissues are broken down to supply energy.

Exogenous metabolism is the metabolism of all the protein ingested in excess of that required by the tissues for maintenance and growth. Endogenous metabolism is the use of proteins in tissues for repair and growth.

[2] NH_2 is split off with enough hydrogen to form ammonia, NH_3. Ammonia combines with carbonic acid to form ammonium carbonate.

Ammonia	Carbonic Acid	Ammonium Carbonate	Ammonium Carbamate	Urea

$$2\,NH_3 + H_2CO_3 \rightarrow (NH_4)_2CO_3 \rightarrow NH_4CO_2\,NH_2 + H_2O \rightarrow NH_2\,CO\,NH_2 + H_2O$$

Werner considers urea to be a compound of ammonia and the keto form of cyanic acid.

[3] The only way in which protein is stored in the body is in the form of new tissue during growth or recovery from a wasting illness, and during pregnancy.

In the classification of proteins given on page 426 it is stated that one of the conjugated proteins is nucleoprotein. Nucleoproteins are the proteins of the nuclei of the cells of the body and are abundant in the nucleated cells of the glandular organs, such as the liver, pancreas, thymus, etc. Foods rich in nucleoproteins are sweetbreads, kidney, roe, liver, and sardines. Foods with a fairly high nucleoprotein content are beef, veal, mutton, pork, chicken, turkey, goose and other game, fish (cod excepted), spinach, asparagus, and beans. In the course of digestion the protein is separated from the nucleic acid and is eventually reduced to amino-acids. The nucleic acid gives rise to substances known as purine bodies. Uric acid is the end-product of the metabolism of purine bodies, from which it arises as a result of oxidation. There is some difference in the products of the hydrolysis of tissue nucleoproteins and food nucleoproteins, but the process is the same and uric acid is the waste product of both. Uric acid resulting from the oxidation of the nucleoproteins of the tissues is classed as endogenous. Uric acid resulting from the oxidation of the nucleoproteins of food is classed as exogenous.

Nutritive value of different proteins. — Proteins vary in their constituents and in their nutritive value. Because of this they are classed as adequate and inadequate proteins. *Adequate* proteins contain all the constituents for the growth and maintenance of the body. *Inadequate* proteins furnish material for energy needs, but not for growth and the repair of tissue waste. The difference between the two kinds seems to lie in the character of the amino-acids of which they are composed. Gelatin is an example of an inadequate protein. It is easily digested and absorbed, undergoes oxidation, which results in the liberation of energy and the production of urea, carbon dioxide, and water, but it does not supply all the material needed for the repair of tissue waste. On the other hand, the casein of milk and the glutenin of wheat contain all the essential amino-acids and can furnish energy, and build tissue.

Energy of food. — After absorption, carbohydrates may, under normal conditions, be oxidized or stored as glycogen or changed into fat; fat may be oxidized or stored and its glyceryl radical may be converted into carbohydrate; protein absorbed as amino-acids may be built up into tissue protein or deaminized and oxidized, or may yield carbohydrate, or share in the production of fat. Energy for the internal and external work which the body does is a constant need, and the body is able to use any or all

of the foods as fuel to produce energy. Consequently, the most convenient way to compare food values is in terms of their energy value.

The energy of food is not used directly as heat, but it is customary to measure it by heat units. To determine the amount of energy in any given food, it is burned and the amount of heat given off is noted. The heat produced is measured in terms of Calories by means of a calorimeter. A large Calorie (Cal.) is the amount of heat required to raise one kilogram (2.2 lb.) of water 1° C., or one pound of water 4° F. The large Calorie (Cal.) is the one referred to in physiology. When undergoing complete oxidation in the calorimeter, the foodstuffs yield the following:

Carbohydrate......	1 gm. — 4.10 Cal.
Fat...............	1 gm. — 9.45 Cal.
Protein...........	1 gm. — 5.65 Cal.

The oxidation of protein in the body is never quite complete, and in the case of all three foodstuffs, there is reason to expect slight losses, due to incomplete absorption from the digestive tube. Consequently, some deductions are made for what is called *losses in digestion.* The figures used in estimating the fuel value of food are:

Carbohydrate.....	1 gm. — 4 Cal.
Fat..............	1 gm. — 9 Cal.
Protein..........	1 gm. — 4 Cal.

Basal metabolism. — This term is used to indicate the rate of energy metabolism of the body, when the subject is lying quiet and relaxed in a room of comfortable temperature, in what is called the "post absorptive" state, *i.e.*, twelve to eighteen hours after the last meal. It is assumed that the digestion and absorption of the last meal is complete at this time. In other words, basal metabolism is the energy required to keep the body alive, to sustain its warmth, to maintain muscle tone and such activities as breathing, heart action, etc.

The metabolism of the body may be determined by direct or indirect methods of calorimetry. The *direct method* consists in placing the subject in a respiration chamber and measuring the amount of heat evolved. By the *indirect method*, the heat given off is computed from the respiratory exchange.

Respiratory quotient. — It has been demonstrated that energy calculated from the amounts of carbon dioxide excreted and oxygen absorbed by a subject lying quietly, exactly equals the heat given off by his body. If we know the volume of carbon dioxide ex-

creted and the volume of oxygen absorbed, the ratio between the two is figured by dividing the volume of carbon dioxide by the volume of oxygen.

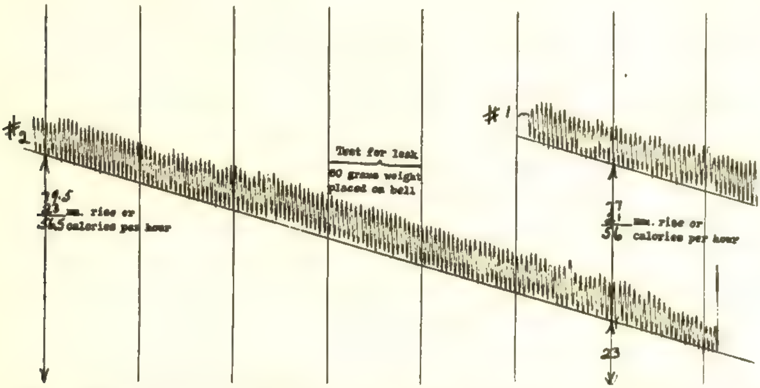


FIG. 227. — BASAL METABOLIC RATE. Rise in oxygen line is 56.5 mm. in 6 min. Miss G. S.'s body surface is 1.53 sq. meters (Du Bois table), age 27 years. The space between two vertical lines represents one minute. This gives a basal metabolic rate of minus 6.7% (within normal range). Respiration 20, pulse 67, temperature 98.6° F.

The amount of oxygen required to burn a given amount of carbohydrate is not the same as that required to burn a similar amount of fat or protein. In the combustion of carbohydrate, the volume of carbon dioxide produced is equal to the volume of oxygen absorbed. The respiratory quotient is, therefore, $\frac{\text{Volume } CO_2 \text{ produced}}{\text{Volume } O_2 \text{ consumed}}$ or R.Q. 1.

There are slight variations in the respiratory quotients of different fats, owing to differences in molecular weight. For human fat, the quotient is .703. For protein, the quotient is 0.8 to 0.82. These figures show that the carbon dioxide produced is generally less than the oxygen which has disappeared in the exchange.

If the combustion of carbohydrate alone were possible, the respiratory quotient would be 1; if only protein were burned, it would be 0.80 to 0.82; if fat, about 0.7.

Under ordinary conditions, the respiratory quotient is about 0.85, but it may vary within rather wide limits.

The basal rate of energy metabolism is used as a starting point for the calculation of total energy requirements for people doing different kinds of work, and as a basis of comparison in the study of abnormal conditions. The basal metabolism of a young man of average weight (70 kilograms or 154 pounds) is about 1700 Calories for a twenty-four-hour day.

Weight. — It is sometimes convenient to estimate basal metabolism in terms of body weight. If the basal rate is 1 Calorie

per kilogram per hour, the adult of 70 kilograms' weight would have a basal metabolism of 1680 Calories for twenty-four hours ($1 \times 70 \times 24 = 1680$).

Body surface. — Calculation of basal metabolism by weight is not as accurate a determination as can be made on the basis of the surface area of the body, because energy requirement, and therefore the food requirement, increases in proportion to surface rather than weight. A table for this purpose has been worked out.[4] According to this table, a man 50 years of age, weighing 70 kilograms and standing 5 ft. 8 in. in height, will have a body surface of 1.83 square meters, and his basal metabolism will be about 39.7 Calories per square meter per hour. His total basal metabolism will amount to 1740 Calories ($1.83 \times 24 \times 39.7$).

The figures obtained by these methods and the figures obtained by actual basal metabolism have been compared for many persons. In over half the cases, the predicted value did not fall more than 5 per cent above or below the actual value, and in only 7 cases was the deviation more than 10 per cent in either direction.

Food. — Over and above the food required to meet the needs of basal metabolism, which represents the bare necessities, it is customary to allow for the influence of food. On an ordinary mixed diet meeting requirements for activity, as much as 10 per cent is allowed for the influence of food.

Work. — Muscular work is the most important of the factors which raise the food requirement of adults above the basic rate. Many experiments to determine the energy expenditure during muscular work have been carried out. The records of these experiments show that even slight changes of position and light muscular effort increase the energy output. For ease in calculating, an attempt has been made to grade muscular activity as (1) very light, (2) light, (3) moderate, and (4) severe. The energy expenditure of an average man for all grades of muscular activity has been worked out by many workers and reported.[5]

(1) The effort involved in sitting at rest is classed as *very light,* and requires about 100 Calories per hour.

(2) *Light* work would be that involving few muscles, such as tailoring or rapid typewriting, and requires about 140 Calories per hour; or the effort expended in walking, which requires about 170 Calories per hour.

[4] See *Basal Metabolism in Health and Disease,* E. F. Du Bois, or *The Foundations of Nutrition,* M. S. Rose.

[5] See *Laboratory Handbook for Dietetics,* by M. S. Rose.

(3) *Moderate* work is the equivalent of the work of a carpenter for a full day, and requires about 240 Calories per hour.

(4) *Severe* work is any work involving much effort and many muscles, and requires about 450 Calories per hour, and in the case

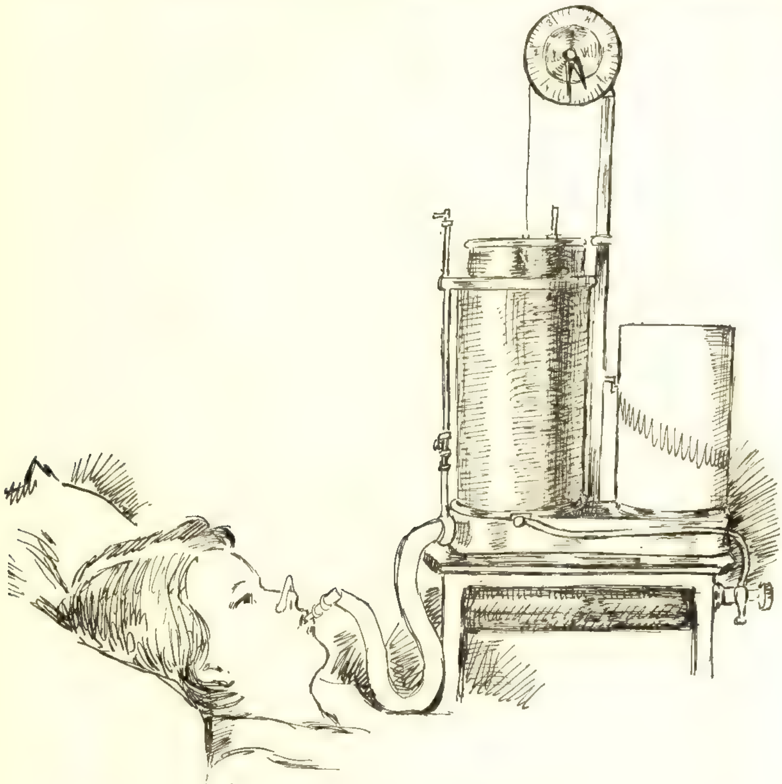


FIG. 228. — A SPIROMETER FOR RECORDING METABOLISM RATES. An inverted chamber containing air is hung from a pulley in another jar with an air-tight seal. As the patient breathes in and out, the chamber falls and rises, writing a line on the revolving drum as shown at right. M. L. is about 12 years old. The average basal metabolism at this age would be about 62 Cals. p r hour.

of a well-trained man exerting himself to top capacity, will require 600 Calories an hour.

Sleep. — In estimating the energy requirement, 0.93 Calories per kilogram per hour should be allowed for sleeping periods. This represents a saving of 7 per cent over the basic metabolic rate and means an expenditure of 65 Calories for 70 kilograms ($0.93 \times 70 = 65.1$).

Total energy requirement of average man. — With these data and a knowledge of the activities of an average man, we can estimate his energy requirement with sufficient accuracy for most dietary purposes.[6]

8 hours of sleep at 65 Calories	=	520 Calories
2 hours of light exercise at 170 Calories	=	340 Calories
8 hours of carpenter work at 240 Calories	=	1920 Calories
6 hours sitting at rest at 100 Calories	=	600 Calories
Total requirement for 24 hours	=	3380 Calories

Protein requirement. — It is recommended that ten to fifteen per cent of the daily Calories should be in the form of protein. When the protein in the diet is excessively high, it raises the metabolism without beneficial effect, and with possible harmful effects. It is at least a wasteful excess and should be avoided. On the other hand, while it is possible to satisfy the nitrogen requirements with less than ten per cent of protein, such a supply does not afford much reserve for such emergencies as loss in digestion, or inability of the body to utilize to good advantage the type of protein supplied, hence it is usually inadvisable to limit the protein of the diet to less than 10 per cent.

Fat requirement. — It is recommended that 30 to 35 per cent of the daily Calories should be in the form of fat. For the average man, this would come to about 100 grams per day. The amount of fat should not exceed the ratio of one gram of fat to four grams of carbohydrate. Evidence is accumulating which indicates that in addition to total fat requirement, care must be taken to include certain fatty acids.

Carbohydrate requirement. — The amount of carbohydrates which can be taken to advantage depends upon the form, starch being capable of good digestion up to 500 grams per day. The assimilation for sugar varies with the kind, but is lower than for starch. In the ordinary diet of a healthy individual the carbohydrates tend to predominate, so that there is seldom necessity for estimating fat and carbohydrate separately.

Stimulants. — Under this heading are included tea, coffee, cocoa, and meat extracts. Tea and coffee owe their stimulating effect to caffeine. Caffeine has a diuretic effect on the kidneys, and a stimulating effect on the nerve centers. It prevents sleepiness, which is probably due to its effect in raising blood-pressure. Tea and coffee increase muscular energy and diminish fatigue. Cocoa, or the chocolate made from it by the addition of sugar, contains nourish-

[6] *Chemistry of Food and Nutrition,* by H. C. Sherman.

ment in the form of carbohydrate, fat, and protein. Its stimulating effects are due to theobromine. Meat extracts contain secretagogues, which stimulate the gastric glands to secretion.

Alcohol. — Alcohol is rapidly absorbed and quickly oxidized. It yields heat, and gives rise to carbon dioxide and water. It is not transformed into fat or glycogen, hence is not stored. Indirectly it may cause obesity in two ways: (1) moderate drinking creates a keen appetite and so favors overeating; (2) the oxidation of alcohol lessens the need for the oxidation of fats, or carbohydrates. Thus fat is spared to be accumulated, or carbohydrates to be changed into it.

Foods to regulate body processes. — It was formerly thought that dietaries furnishing sufficient energy and protein would always be adequate as regards the mineral salts. This assumption is not safe in the case of calcium, phosphorus, iron, and in some regions iodine. The amount of calcium and phosphorus needed daily is relatively large, and on this account there is a possibility of serious shortage, unless definite provision is made for it.

The amount of iron needed daily is very minute, but the quantities in food materials are also minute, consequently, it is not wise to trust to chance that the supply will be adequate. Practically, if the requirements for calcium, phosphorus, and iron are met, there is strong likelihood that the other mineral elements will be adequately furnished, for foods which supply the former will provide many of the latter. H. C. Sherman, as a result of extensive work in his own and other laboratories, states, "The evidence thus far available indicates an average minimum requirement for equilibrium, per man per day for 0.45 gm. calcium, 0.88 gm. phosphorus, and 0.010 gm. of iron."

In order to provide a liberal margin of safety, it is suggested that the standard allowance be set 50 per cent above the indicated average minimum. This would give a dietary standard of calcium, 0.68 gm., phosphorus, 1.32 gm., and iron. 0.015 gm.

This allowance of calcium is not adequate for children, or for women during pregnancy. The requirement of a growing child is at least 1 gram of calcium and phosphorus per day. The source of calcium affects its utilization. Milk is the best source.

The calcium requirement for women is increased during pregnancy, because the mother must provide a store of calcium upon which the fetus draws for the development of its skeleton. Lusk [7] cites a study of the calcium retention of a pregnant woman for 23 weeks, during which time the fetus retained 30.12 grams, and the mother retained only 4.2 grams! Estimating the mother's requirement at 4 grams per week, the addition of 2 grams per week

[7] Graham Lusk, *Science of Nutrition.*

for the fetus would mean a 50 per cent increase in the diet of a pregnant woman, so that she should have at least three-quarters of a gram of calcium per day during the latter half of her pregnancy, if she is to be fully protected against withdrawal of calcium from her bones and teeth.

During the early months of lactation, the need for calcium is equal to the need during the last weeks of pregnancy, and during the later months of lactation the demands upon the mother will raise her total calcium requirement to at least one gram per day. This need is best met by a quart of milk daily.

Iron. — Not only the red cells of the blood, but all the cells of the body contain iron. It serves to carry oxygen and to activate cell functions. The amount in the body is about one-tenth of an ounce. Because of the limited storage of iron in the body, foods containing iron should be included in the daily diet. These foods are green vegetables, egg-yolk, liver, fruits, and whole grains.

When born, a baby has a special store of iron in its body, which serves during the period of lactation. During the latter half of the first year, egg-yolk and iron-bearing vegetables should be added gradually to the diet, so that, as the reserve iron is used up, fresh supplies will be available. In premature infants this special store of iron is absent. Preparations of iron and copper are added to the milk.

Iodine. — Iodine is essential to the thyroid gland, which regulates basal metabolism and is a factor in normal growth. The thyroid utilizes inorganic iodine in the preparation of thyroxin, the hormone of the internal secretion. Sherman states that the amount of iodine provided should be sufficient to meet the daily losses from the body and to maintain within the body such a store as is needed to enable the thyroid gland to manufacture sufficient amounts of thyroxin for distribution throughout the body.

It is estimated that a full-grown, healthy man has about 25 milligrams of iodine in his 70 kilograms of body weight. To maintain this supply, it is estimated that a normal adult requires about 0.000014 gram of iodine daily.[8] When larger amounts are furnished, a reserve supply is built up in the body. Milk, leafy vegetables, and fruits grown in nongoitrous regions are the best sources of iodine supply. Fresh and canned salmon, cod, halibut, haddock, lobsters, and oysters are sources of supply.

Factors affecting basal metabolism. — These factors are age, sex, temperature, and the internal secretions.

Age. — During the first week or two of life, the basal metabolism of the baby is below the adult rate, but it gradually rises and by the end of the first year, or the early part of the second, it may exceed the adult rate. From this time it gradually declines; at five years it is about 60 Calories per square meter of body surface per

[8] Henry C. Sherman, *Chemistry of Foods and Nutrition.*

hour; at twelve years, it is about 50. Just before puberty, in both boys and girls, there is a period when the decline is arrested, and there may be an increase. These figures suggest that children have a high food requirement for maintenance. Over and above this, generous provision for growth and activity is essential.

Between the ages of twenty and forty, basal metabolism is usually constant, at about 40 Calories per square meter per hour for an adult male. About fifty years of age, this requirement begins to fall, and between seventy and eighty, it is about 35.

Sex. — Several investigators report a higher metabolic rate in men than in women of the same height and weight. It is thought that this may be due to a difference in the average composition of the body. Pregnancy and lactation make heavy demands upon mothers and increase the metabolic rate.

Temperature. — Whenever the body temperature rises, heat production increases in direct proportion. Studies of basal metabolism in fevers show an increase of 7.2 per cent for every degree of Fahrenheit above normal. Hence, fevers are accompanied by a loss of weight, unless the loss is compensated by an increased intake of food.

Temperature slightly below that of the body causes the peripheral blood-vessels to contract. As the temperature falls, a feeling of tone develops, and the metabolic rate is increased. There is also an increase in muscular activity.

Internal secretions. — Some of the internal secretions, notably that of the thyroid, influence metabolism by stimulating the heart action and the respiratory rate and increasing oxidations. Basal metabolism is increased in exophthalmic goiter, malaria, typhoid, and tuberculosis, accompanied by fever. It is decreased in hypothyroidism and myxedema.

Vitamins. — The vitamins required for growth are the same as those required for maintenance. An adult may undergo a shortage of vitamins for a considerable time without showing distinct injury, but during the period of growth children show detrimental effects more quickly. Growth itself is a strain, and the resisting powers of the tissues are not developed; these two factors make the need of vitamins in the diet of children most urgent.

Vitamin B and probably vitamin C also have a pronounced effect in stimulating appetite. Consequently, a liberal supply of these vitamins results in the eating of more food, and the diet may be raised from an inadequate to an adequate level by the addition of vitamin B to the food.

Water. — In health the *water* balance of the body is maintained by a liberal intake. It is estimated that two quarts daily are an average allowance.

Body equilibrium. — This term is used to describe the normal adult condition, when the intake of food is balanced by corresponding excretions and the individual maintains a constant weight.

Nitrogen equilibrium. — The nitrogenous portion of the protein molecule is not stored in the body but is eliminated chiefly in the urine, and to a limited extent in the feces. The body is said to be in nitrogen equilibrium when the amount of protein nitrogen taken into the body is equal to the amount eliminated in the excreta. If there is a plus balance in favor of the food, it means that protein is being made into body protoplasm, and this is an ideal condition during the period of growth or convalescence from wasting illness. If the balance is minus, it means that the body is burning its own protein to supply its needs.

Carbon equilibrium. — When the carbon of the food and the carbon eliminated in the excreta (carbon dioxide, urea, etc.) balance, the body is said to be in carbon equilibrium. It is possible to be in nitrogen equilibrium and yet be gaining or losing weight.

If the supply of food is greater than the body needs and the excess is stored as glycogen or fat, the carbon absorption is greater than the carbon excretion (gaining weight). If the supply of energy-yielding food is less than the body needs, some of the body fat may be oxidized and the carbon excretion will be greater than the carbon intake (losing weight).

SUMMARY

Absorption
- Passage of digested food material from the cavity of the alimentary canal to the blood.
- **Determining conditions**
  1. Character of epithelial cells.
  2. Area of surface for absorption.
  3. Length of time food is in contact with absorbing surface.
  4. Concentration of digested material present.
- **Small Intestine**
  - These conditions are more fully realized.
  1. Selective action of epithelial cells.
  2. Circular folds and villi increase internal surface.
  3. Food remains for several hours.
  4. Products of digestion higher in intestine, lower in blood.

Absorption

- **Paths of absorption**
  1. Central lymph channel of villus absorbs glycerin and fat, empty into larger lymph-vessels, then into thoracic duct, superior vena cava, and right auricle of heart.
  2. Capillaries of villi absorb sugars, amino-acids, and some of the glycerin and fatty acids, carry them to portal tube, then to liver.
- **Stomach**
  - Alcohol and alcoholic solutions absorbed.
  - Small amounts of sugar, amino-acids may be.
  - Water is not absorbed.
- **Large Intestine**
  - Limited absorption of digested foodstuffs, marked absorption of water.

Place of absorption of digested foodstuffs

- Water — absorbed in small intestine, but loss made good by secretion, marked absorption in large intestine.
- Salts — absorption may take place from any part of intestines, depends upon the concentration of the solution, and the nature of the salt.
- Simple sugars — pass into capillaries and then by way of the portal tube to the liver.
- Fatty acids and glycerin — absorbed by lacteals in the villi synthesized to form fat, and fat is carried to thoracic duct, which empties into left subclavian vein.
- Amino-acids — pass into capillaries of villi.

Metabolism

- Includes all processes involved from time food enters the body until it is excreted.
- In this chapter metabolism is limited to include only changes that occur in foodstuffs from time of absorption to elimination.
- **Consists of**
  - Anabolism — processes by which living cells take food substances from the blood and make them into protoplasm and stored products.
  - Catabolism — processes by which living cells change into simpler substances, (*a*) part of their own protoplasm, or (*b*) stored products.
  - Catabolic processes
    1. Simple splitting of complex molecules into simpler ones.
    2. Hydrolysis or the splitting of complex molecules into simpler ones with the absorption of water.
    3. Oxidation or the union of oxygen with the constituents of the cells. Oxidation and reduction occur at the same time.
- **Functions**
  - Growth and repair of tissue.
  - Release of chemical energy in the form of heat, nervous activity, muscular activity, etc.

Metabolism

- **Factors**
  1. Oxygen absorbed from lungs.
  2. Enzymes secreted by tissue cells.
  3. Autacoids secreted by the ductless glands.
  4. Vitamins furnished by the food.
  5. The nervous system.

Metabolism of Carbohydrates

- **History**
  1. Supply regulated by diet.
  2. Storage provided for temporarily by liver, muscles, and cells of tissues. Simple sugars stored as glycogen.
  3. Consumption controlled by the energy needs of the tissues.
- **Processes**
  - Glycogenesis or the production of glycogen in the liver.
  - Glycogenolysis or the conversion of glycogen to sugar according to body needs.
  - Glycolysis or the consumption of sugar in the tissues.
  - Glycosuria or loss of sugar in the urine.
- **Regulation of blood-sugar**
  - **Insulin,** the hormone of the internal secretion of the pancreas, is essential. It regulates the metabolism of glucose. In derangements of carbohydrate metabolism it produces four marked effects.
    1. Restores the power to utilize the glucose of the blood.
    2. Accelerates the synthesis of sugar to glycogen.
    3. Restricts production of sugar from protein and fat.
    4. Counteracts tendency to acidosis.
  - **Administration**
    - Ineffective by mouth.
    - Injected under skin.
  - There may be a sugar-regulating center in medulla.
  - Control may be exercised indirectly through adrenal glands.
  - Influenced by emotional excitement.
- **Functions**
  - Furnish main source of energy for muscular work and all the nutritive processes.
  - Help to maintain the body temperature.
  - Protect the body tissues by forming reserve fund for time of need (glycogen).
  - Excess carbohydrates are converted into adipose tissue.
  - May be used in constructive processes.
  - Assist in oxidation of fats.
- **Waste products**
  - When completely oxidized, the waste products are carbon dioxide and water.
- **Derangements of**
  1. Glycogenesis breaks down, giving rise to alimentary glycosuria.
  2. Glycogenolysis breaks down.
  3. Glycolysis breaks down.
  4. Normal impermeability of the kidneys breaks down.

Metabolism of Fats

- **Reconstruction** — In act of passing through epithelial cells of villi, glycerin and fatty acids combine to form fat.
- **Dependent upon lipase.**
- **Functions**
  - Serve as fuel, yield heat and other forms of energy.
  - Stored as adipose tissue.
  - Synthesized to form compound fats and fat-like substances.
  - Glyceryl radical may be converted to glucose.
- **Oxidation**
  - First step brought about by lipase.
  - Lipase controls output of fat to blood.
  - Oxidation takes place after lipase has acted.
  - Waste products are carbon dioxide and water.
  - When oxidation is incomplete, acetone bodies are formed.
- **Body Fat**
  - Formed from the fats, carbohydrates, and proteins of food in order named.
- **Obesity**
  - May be caused by eating more food than body needs, by lack of exercise or both.
  - May be due to endocrine disturbances.

Metabolism of Proteins

- Absorbed as amino-acids. From villi pass to portal tube thence to liver, and general circulation.
- Tissues select amino-acids
  1. To build new tissue.
  2. To repair wastes of metabolism.
- Amino-acids not used in building up protoplasm are deaminized and split into non-nitrogenous and nitrogenous portion.
- Non-nitrogenous portion oxidized to CO_2 and H_2O, or converted into glycogen.
- Nitrogenous portion passes through a series of changes — final waste product urea.
- **Classification**
  - Endogenous, includes building up of amino-acids to tissue protoplasm and final disintegration to creatinine and urea.
  - Exogenous, includes reactions affecting uncombined amino-acids, formation of urea from nitrogenous portion, and glucose from non-nitrogenous portion, also secondary production of glycogen.
- **Nucleoproteins**
  - Nucleoproteins — process of digestion, protein separated from nucleic acid and reduced to amino-acids, history same as above.
  - Nucleic acid gives rise to purine bodies of which uric acid is waste product.
  - Endogenous uric acid from nucleoproteins of tissue cells.
  - Exogenous uric acid from nucleoproteins of food.
- **Nutritive Value**
  - **Adequate** proteins contain all the materials for maintenance and growth of tissue.
  - **Inadequate** proteins serve same purpose as carbohydrates and fats.

- **Amount of food needed**
  - Food source of energy for tissue building or work.
  - **Calorie**
    - Unit of measurement for heat production.
    - Large Calorie = quantity of heat necessary to raise one kilogram (2.2 lb.) of water 1 degree Centigrade or one pound of water 4 degrees Fahrenheit.
  - **Carbohydrates** — 1 gm. — 4 Cal.
  - **Fat** — 1 gm. — 9 Cal.
  - **Protein** — 1 gm. — 4 Cal.
  - **Total Metabolism**
    - Basal metabolism — energy necessary to keep body alive.
    - Cost of digestion — energy expended in working over food.
    - Energy required for work.
  - **Respiratory Quotient**
    - Ratio between carbon dioxide excreted and oxygen absorbed. Ratio between the two is figured by dividing the volume of carbon dioxide by the volume of oxygen.
  - **Factors to consider**
    - Weight, body surface, food, work, and sleep. May be estimated at 1 Calorie per kilogram of weight, per hour ($1 \times 70 \times 24 = 1680$ Calories).
  - **Distribution**
    - Proteins — 10 to 15 per cent.
    - Fats — about 100 grams essential. Ratio of fats to carbohydrates about 1–4.
    - Carbohydrates — depends upon form in which taken, also on amount of fat.

- **Accessory articles of food**
  - **Flavors and Condiments**
    - Have no nutritive value, but increase the secretion of gastric fluid.
  - **Stimulants**
    - Tea and coffee — stimulating action due to caffein
    - Cocoa
      - Contains carbohydrate, fat, and protein.
      - Stimulating effects due to theobromine.
    - Meat Extracts
      - Contain secretagogues which stimulate the gastric glands to secretion.
  - **Alcohol**
    - Oxidized rapidly, yields heat.
    - Waste Products
      - Carbon dioxide.
      - Water.
    - Favors Obesity
      - Moderate drinking creates keen appetite, and thus favors overeating.
      - Lessens need for oxidation of fat or carbohydrates, hence these are spared to accumulate.

Foods to regulate Body Processes

- Mineral salts are calcium, iron, phosphorus, sulphur, magnesium, potassium, sodium, iodine, chlorine, fluorine, and silicon.
- Not safe to leave calcium, phosphorus, iron, and iodine to chance.
- Standard daily allowance

Calcium	0.68 gm.
Phosphorus	1.32 gm.
Iron	0.015 gm.
Iodine	0.000014 gm.

- *Vitamins* — necessary to prevent specific diseases and malnutrition. Amounts of each required not known.
- Diet which meets all nutritive requirements, and in which milk, vegetables, and some fresh food is included, is thought to meet vitamin requirement.
- *Water* — sufficient to make good amount lost from tissues and to serve purposes listed. Estimated that daily requirement is about eight glasses.

Nitrogen Equilibrium

- Condition when the amount of protein nitrogen taken into the body in food is equal to the amount eliminated in the excreta.
- Plus balance in favor of food means growth of new tissue — favorable condition during growth and convalescence from wasting illness.
- Minus balance — means body is burning its own proteins.

Carbon Equilibrium

- When the carbon of the food and the carbon eliminated balance, the body is in carbon equilibrium.
- Carbon absorption greater than carbon excretion — gaining weight.
- Carbon excretion greater than carbon intake — losing weight.

CHAPTER XXI

WASTE PRODUCTS; EXCRETORY ORGANS; URINE

In the previous chapters we have seen that the blood is constantly supplied by means of the respiratory and digestive mechanisms with the chemical substances it requires to maintain the life, growth, and activity of the body. These substances, entering the current of the blood, are carried to all the cells and are constantly combining with the chemical substances of which these cells are composed. One of the results of these chemical combinations is the formation of waste products, which must be removed from the body, as many of them are toxic.

WASTE PRODUCTS

The waste products of the body are carbon dioxide, water, organic and inorganic salts, hair, nails, dead skin, and the indigestible and undigested portions of foods eaten.

The wastes of cell metabolism may be listed as follows:

1. Soluble Salts { Nitrogenous salts, *e.g.*, urea. / Inorganic salts, *e.g.*, sodium chloride.
2. Liquid — Water.
3. Gas — Carbon dioxide.

All of these wastes are classed as excreta and the process by which they are removed from the body as excretion or elimination.

EXCRETORY ORGANS

The organs that function as excretory organs and the products that they eliminate may be tabulated as follows:

	Essential	Incidental
Lungs..........	Carbon dioxide	Water, heat.
Kidneys........	Water and soluble salts, resulting from metabolism of proteins, neutralization of acids, etc.	Carbon dioxide, heat.
Alimentary canal	Solids, secretions, etc.	Water, carbon dioxide, salts, heat.
Skin...........	Heat regulatory	Water, carbon dioxide, salts, hair, nails, and dead skin.

This chapter includes a description of the urinary system, which consists of the following organs: two *kidneys*, which form the urine from materials taken from the blood; two *ureters*, ducts which

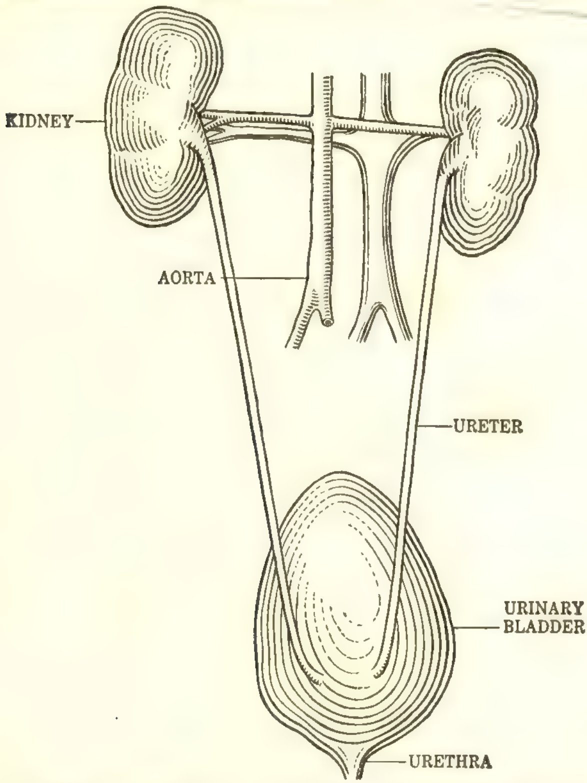


FIG. 229. — THE URINARY SYSTEM. Viewed from behind.

Carry

~~convey~~ the urine away from the kidneys; the *bladder*, a reservoir for the reception of urine; the *urethra*, a tube through which the urine passes from the bladder and is finally voided.

KIDNEYS

The kidneys are two compound tubular glands, placed at the back of the abdominal cavity, one on each side of the spinal column and behind the peritoneal cavity. They correspond in position to the space included between the upper border of the twelfth thoracic and the third lumbar vertebræ. The right is a little lower than the left, because of the large space occupied by the liver.

Each kidney with its vessels is imbedded in a mass of fatty tissue termed an adipose capsule. The kidney and the *adipose capsule* are surrounded by a sheath of fibrous tissue called the *renal fascia.* The renal fascia is connected to the fibrous tunic of the kidney by numerous trabeculæ, which are strongest at the lower end. The kidney is held in place partly by the renal fascia, which blends with the fasciæ on the quadratus lumborum and psoas major, also with the fascia of the diaphragm, and partly by the pressure and counter pressure of neighboring organs.

The kidneys are bean-shaped, with the medial or concave border directed toward the median line of the body. Near the center of the concave border is a fissure called the *hilum* which serves as a passageway for the ureter, and for the blood-vessels, lymph-vessels, and nerves going to and from the kidney.

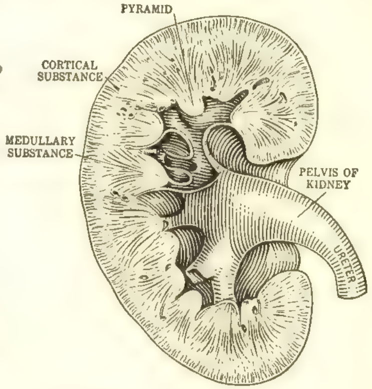


FIG. 230. — DIAGRAMMATIC LONGITUDINAL SECTION OF THE KIDNEY. Each kidney is about 11.25 cm. long, 5 to 7.5 cm. broad, and 2.5 cm. thick, and weighs about 135 gm. (Henle.)

Anatomy of the kidney. — Each kidney is covered by a thin but rather tough envelope of fibrous tissue, which can be readily pulled off. At the hilum of the kidney the capsule becomes continuous with the outer coat of the ureter. If a kidney is cut in two lengthwise, it is seen that the upper end of the ureter expands into a basin-like cavity, called the *pelvis* of the kidney. The substance of the kidney consists of an outer portion called the cortical substance (cortex) and an inner portion called the medullary substance (medulla). Between the cortical and medullary substances are the arterial and venous arches.

The *cortical substance* contains the glomerular capsules, the convoluted tubules, arteries, and veins.

The *medullary substance* contains conical masses, called the renal pyramids, the basis of which are directed toward the circumference of the kidney, while the apices converge toward the pelvis, where they form pointed projections called papillæ, which are received by the cup-like cavities or *calyces* of the pelvis. The cortical substance penetrates for a variable distance between the pyramids, separating and supporting them. These inter-pyramidal extensions are called

the renal columns (Bertini)[1] and support the blood-vessels. The bulk of the kidney substance, both in the cortex and medulla, is composed of little tubes or tubules, closely packed together, having only just enough connective tissue to carry a large supply of blood-vessels and a certain number of lymphatics and nerves.

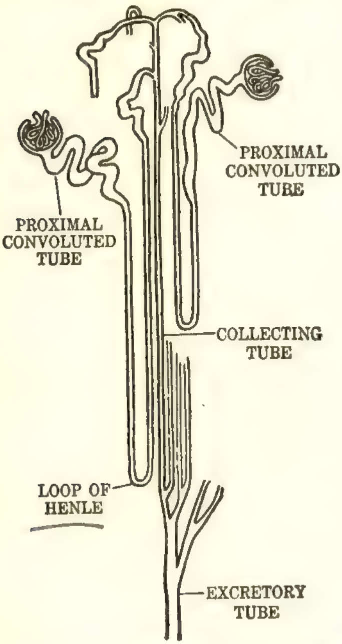


FIG. 231. — DIAGRAM OF THE COURSE OF TWO RENAL TUBULES.

Renal tubules. — Examined under the microscope, it is seen that the renal tubules begin as little hollow globes, called the *glomerular capsules* (capsules of Bowman[2]), in the cortex of the kidney. These capsules are joined to the tubules by a constricted neck, and the tubules, after running a very irregular course, open into straight collecting tubes, which pour their contents through their openings in the pointed ends or papillæ of the pyramids, into the calyces of the kidney.

The tubules may be separated into a secreting part, consisting of the glomerular capsule, the convoluted tubule, the loop of Henle,[3] and a collecting part consisting of the straight and central tubules. The tubules are composed of basement membrane, lined throughout by epithelial cells. The epithelial cells vary in different parts of the tubule. In the secreting part they are cylindrical in shape, granular in appearance, and suggest active secretory cells.

Pyramid. — These collecting tubules *en masse,* together with interstitial tissue, blood-vessels, and lymphatics, make a pyramid. The number of pyramids varies from eight to eighteen.

Renal (or Malpighian)[4] corpuscles. — In the cortical portion of the kidney are found renal corpuscles which consist of two parts: (1) a minute tuft of capillaries called a *glomerulus,* surrounded by (2) a closed capsule, called the *glomerular capsule,* which is the beginning of a renal tubule. The investment of the glomerulus by the

[1] Exupere Joseph Bertini, French anatomist, 1712–1781.
[2] Sir William Bowman, 1816–1892, English anatomist and physician.
[3] Friedrich Gustav Jakob Henle, German anatomist and physiologist, 1809–1885.
[4] Marcello Malpighi, 1628–1694, Italian, taught at University of Bologna, Italy.

capsule is double and complete except at one point, where an afferent vessel enters and an efferent vessel leaves.

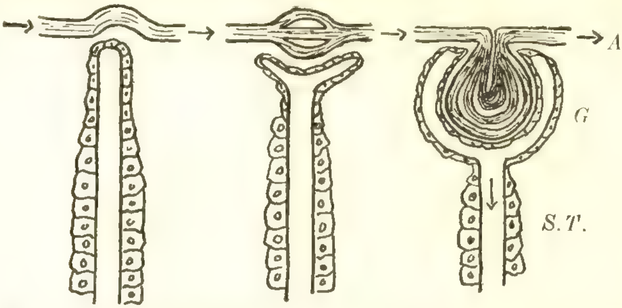


FIG. 232. — DIAGRAM SHOWING STRUCTURE OF RENAL CORPUSCLE. *A*, artery; *G*, glomerulus surrounded by a glomerular capsule; *S. T.* secreting tubule. The glomerulus is a device for securing a large capillary surface where elimination can take place. The tortuous course of the secreting tubules which renders them immensely long, serves to increase the secreting surface of these structures. The complexity of the diagrams increases from left to right, that on the right representing a glomerulus in a schematic way.

The blood-supply of the kidney. — The kidney is abundantly supplied with blood by the renal artery, which is a branch of the abdominal aorta. Before entering the kidney at the hilum each artery divides into several branches. These arteries have two destinations: (1) into the cortical substance, and (2) into the medullary substance.

(1) When the arteries reach the boundary zone between the cortex and the medulla, the branches divide laterally and form more or less complete arches. From the convexity of these arches vessels pass through the cortex (*interlobular*), giving off at intervals tiny arteries, each of which enters [5] the dilated commencement or capsule of a renal tubule. These tiny arteries, entering the capsule, are spoken of as afferent vessels. They push the thin walls of the capsule before them, break up into a knot of capillary vessels, called a *glomerulus*, and finally issue from the capsule as efferent vessels, near the point at which the afferent vessel entered. These efferent vessels are much smaller than the afferent vessels. They break up into a close meshwork or plexus of capillaries around the tubules, before they unite to form the larger vessels and pour their contents into the veins. These veins terminate in venous arches between the cortex and medulla.

[5] The artery does not penetrate the wall of the capsule, but the knot of capillary vessels is contained within the capsule, as the heart is contained within the pericardium.

(2) From the concavity of the arches straight arterioles run through the boundary zone of the medulla and break up into a number of capillaries, which are in relationship with the loop of Henle and the collecting tubules. The blood is collected from the medullary substance by straight veins which open into the venous

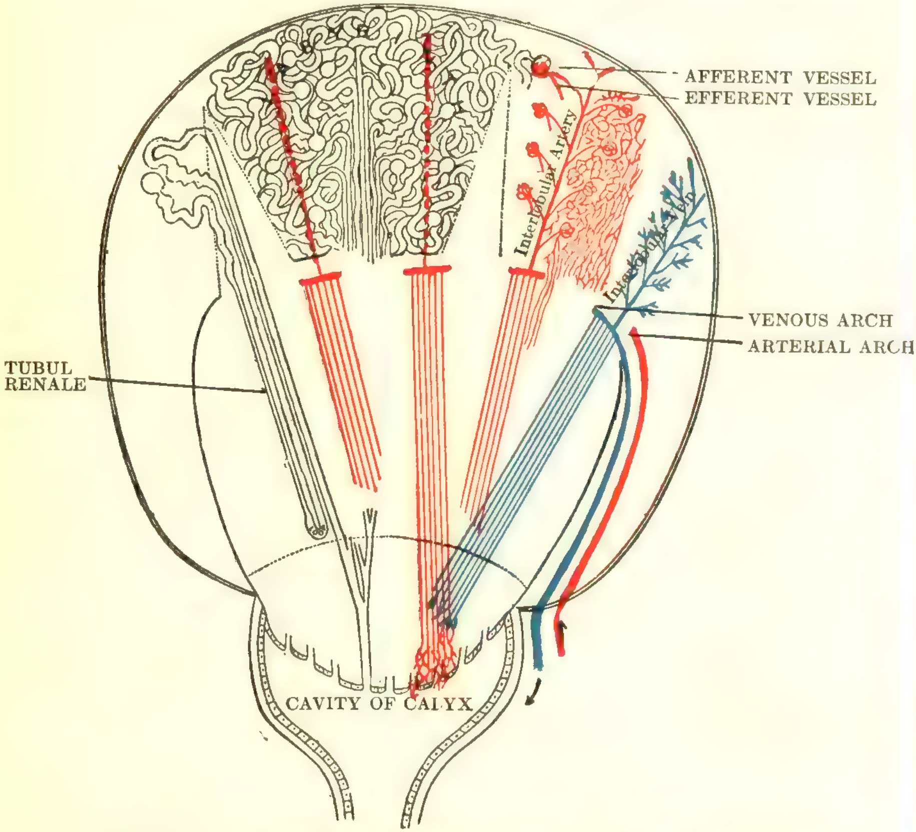


Fig. 233. — Diagram of a Vertical Section of a Lobe of the Kidney Showing the Arrangement of Tubules and Blood-Vessels in the Lobe. See Fig. 231 for an enlarged view of the tubule shown on the left, and Fig. 234 for an enlarged view of arrangement of blood-vessels shown on the right. The calyx embraces the apex of the pyramid. It is lined with epithelium, which continues from it over the apex, the latter being perforated with the many apertures of excretory tubes. (Gerrish.)

arches. The venous arches converge to form the renal vein, which emerges from the kidney at the hilum and opens into the inferior vena cava.

The kidney receives blood from only one artery, and this blood serves the purposes of nourishment and the purposes of excretion.

Nerves. — The nerves of the kidneys are derived from the *renal plexus*, which is formed by branches from the celiac plexus, the aortic plexus, and from the lesser and lowest splanchnic nerves. They accompany the renal arteries and their branches, and are distributed to the blood-vessels. They are vasomotor nerves, and by

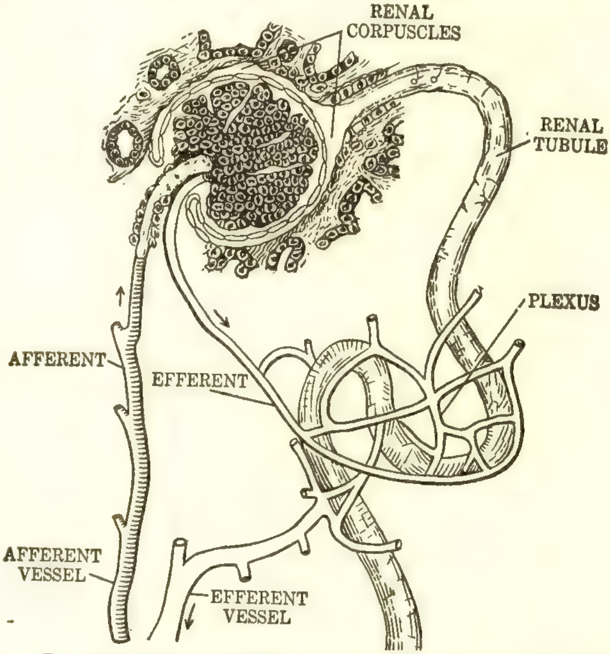


FIG. 234. — PLAN OF THE BLOOD-VESSELS CONNECTED WITH THE TUBULES.

regulating the contraction and dilatation of the blood-vessels they control the circulation of the blood in the kidney.

Function of the kidneys. — The function of the kidneys is to separate the constituents of urine from the blood, and thus help to maintain the normal composition of the blood. The kidneys extract almost all the protein waste, the greater part of the salts not needed by the blood, and about half of the excess water. The amount of water removed by the kidneys varies considerably and is chiefly dependent upon the activity of the sweat-glands. The kidneys also extract foreign substances, such as toxins, whether formed in the body, or taken into the body from outside. The concentration of urine, and not the quantity, is our criterion for judging the amount of work done by the kidneys. It is probable that they are most severely taxed when they have to remove from the blood a maximum of dissolved solids in a minimum of water.

Secretion of urine. — The secretion of urine is a constant process. The exact way in which the kidneys secrete the urine is not known, but it is thought to depend upon three chief factors:

1. The capillary blood pressure in the glomeruli. It is estimated that in each kidney there are several million glomeruli.
2. The velocity of the blood flow through the renal vessels.
3. The physiological activity of the cells lining the renal tubules.

Several theories[6] of the way in which urine is secreted have been proposed, one of which is as follows:

Into each hollow capsule which forms the beginning of a renal tubule an afferent vessel enters. This vessel breaks up into capillaries which form a bunch of looped and twisted blood-vessels called a *glomerulus.* The walls of the capsule being double, the glomerulus pushes back the inner wall or visceral layer, until the capsule is entirely filled, leaving only a small space between it and the outer wall or parietal layer. The blood in the glomerulus is only separated from the interior of the tubule by the thin walls of the capillaries and the inverted wall of the capsule. The vessel (afferent) which enters the capsule is larger than the issuing (efferent) vessel, and during its passage through the glomerulus, the blood is subjected to considerable pressure. As a result of this, a transudation of the watery constituents of the blood, with some dissolved salts, takes place through the walls of the blood-vessels and the walls of the capsule into the capsular space, then into the tubule. It is probable that in the loop of Henle there is a reabsorption of some of these dissolved substances (glucose, salts, etc.).

After leaving the capsule, the efferent vessel communicates with other similar vessels, which together form a meshwork or plexus of capillaries closely surrounding the tubules, so that the blood is again brought into close communication with the tubules. The tubules are lined with cells, and these cells appear to have the power of selecting from the blood some of the dissolved substances (especially the urea).

Diuretics is the name given to drugs (caffeine, digitalis, etc.) which stimulate the activity of the renal cells, and *diuresis* is the term applied to the increased secretion of urine. When the increase is marked and long-continued, it is called *polyuria.*

The ureters. — The ureters are two tubes which convey the urine from the kidneys to the bladder. Each ureter commences as a number of cup-like tubes or calyces, which surround the renal

[6] For review of the various theories, consult physiologies listed in the bibliography.

papillæ. The calyces (varying in number from 7 to 13) join and form two or three short tubes, which unite and form a funnel-shaped dilatation called the *renal pelvis*. From the pelvis the ureter proper, a cylindrical tube, passes to the fundus of the bladder. Each tube is about 25–30 cm. long (10–12 in.) and about 4–5 mm. ($\frac{1}{5}$ in.) in diameter. The walls of these tubes consist of three coats: an outer fibrous coat, a middle muscular, and an inner mucous lining. The contractions of the muscular coat produce peristaltic waves, which commence at the kidney end of the ureter and progress downward.

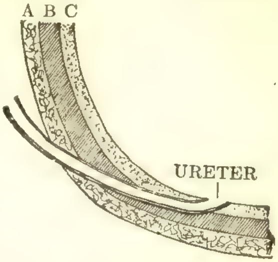


FIG. 235. — DIAGRAM SHOWING ENTRANCE OF URETER INTO BLADDER. *A*, fibrous coat; *B*, muscular coat; and *C*, mucous coat.

BLADDER

The bladder is a hollow muscular organ situated in the pelvic cavity, behind the pubes, in front of the rectum in the male, and in front of the anterior wall of the vagina, and the neck of the uterus, in the female. It is a freely movable organ, but is held in position by folds of peritoneum and fascia. During infancy it is conical in shape and projects above the upper border of the pubes into the hypogastric region. In the adult, when quite empty, it is placed deeply in the pelvis; when slightly distended it has a round form; but when greatly distended, it is ovoid in shape and rises to a considerable height in the abdominal cavity. It has four coats: (1) The **serous** coat is a reflection of the peritoneum, and only covers the superior surface and the upper part of the lateral surfaces. (2) The **muscular** coat has three layers, an inner longitudinal, middle circular, and outer longitudinal. The circular fibers are collected into a layer of some thickness around the opening of the bladder into the urethra. These circular fibers form a sphincter muscle which is normally in a state of contraction, only relaxing at intervals, when the accumulation of urine within the bladder renders its expulsion necessary. (3) The **submucous** coat consists of areolar connective tissue and connects the mucous and muscular coats. (4) The **mucous** membrane lining the bladder is continuous with that lining the ureters and the urethra. This coat is thrown into folds or rugæ when the bladder is empty.

There are three openings into the bladder. The two ureters open into the lower part about half an inch from the median plane.

The urethra leads from the bladder, its vesical opening lying in the median plane below and in front of the openings of the ureters.

Function. — The bladder serves as a reservoir for the reception of urine. The capacity of the bladder varies. When moderately distended, it holds about one-half liter (about one pint).

The urethra. — In the female the urethra is a narrow membranous canal which extends from the bladder to the external orifice, which is called the meatus urinarius. It is placed behind the symphysis pubis, and is imbedded in the anterior wall of the vagina. Its diameter, when undilated, is about 6 mm. ($\frac{1}{4}$ in.) and its length is about 3.8 cm. ($1\frac{1}{2}$ in.). Its direction is obliquely downward and forward, its course being slightly curved, with the concavity directed forward and upward. Its external orifice is the narrowest part and is located between the clitoris and the opening of the vagina.

The walls of the urethra consist of three coats: (1) an outer muscular coat, which is continuous with that of the bladder, (2) a thin layer of spongy tissue, containing a plexus of veins, and (3) a mucous coat, which is continuous internally with that lining the bladder and externally with that of the vulva.

The male urethra is about 20 cm. (8 in.) long. It is divided into three portions: (1) the prostatic, which runs vertically through the prostate, (2) the membranous, which extends between the apex of the prostate and the bulb of the urethra, and (3) the cavernous portion, which extends from the membranous to the external orifice.

The male urethra is composed of (1) mucous membrane, which is continuous with the mucous membrane of the bladder and is prolonged into the ducts of the glands that open into the urethra, and (2) a submucous tissue, which connects it with the structures through which it passes.

Micturition. — Urine is secreted continuously by the kidneys. It is carried to the bladder by the ureters, and at intervals is expelled from the bladder through the urethra. The act by which the urine is expelled is called micturition. The desire to urinate is due to sensory stimulation in the bladder itself caused by pressure of urine, or reflex stimulation. The act is essentially a reflex through the central nervous system.

Involuntary micturition or incontinence. — Involuntary micturition may occur as the result of lack of consciousness, and as the result of spinal injury involving the nerve centers which send nerves of control to the bladder. It may be due to a want of *tone* in the muscular walls, or it may result from some abnormal

irritation due to irritant substances in the urine, or to disease of the bladder (cystitis). Excessive nervousness may provoke the desire to urinate when there is only a small amount of urine in the bladder. This desire may also be aroused by visual and auditory impressions such as the sight and sound of running water.

In young infants incontinence of urine is normal. The infant voids whenever the bladder is sufficiently distended to arouse a reflex stimulus. Children vary markedly in the ease with which they learn to control micturition and defecation. During the first year, some children can be taught to associate the act with the proper time and place. By the second year, regular training in habit formation[7] and proper feeding should enable the child to inhibit the normal stimulus and control micturition, at least during the day. Control of micturition at night is a habit requiring longer practice, and is usually formed by the end of the second year. When involuntary voiding occurs at night with any degree of regularity after the third year, it is called enuresis. If this is not caused by nervous instability or irritation of the bladder, it will usually yield to proper training.

Retention of urine. — Retention or failure to void urine may be due to: (1) some obstruction in the urethra or in the neck of the bladder, (2) nervous contraction of the urethra, and (3) dulling of the senses so that there is no desire to void. In the last two conditions retention is often overcome by measures which induce reflexes, *i.e.*, pouring warm water over the vulva, or the sound of running water. If micturition does not occur, and the bladder is not catheterized, distention of the organ may become extreme, and there is likely to be constant leakage, or involuntary voiding of small amounts of urine without emptying the bladder. This condition is described as retention with overflow.

Suppression of urine. — A far more serious condition than retention is the failure of the kidneys to secrete urine. This is spoken of as suppression or *anuria.* Unless suppression is relieved, a toxic condition known as uremia will develop. When the secretion of urine is decreased below the normal amount the condition is spoken of as *oliguria.*

THE URINE

Normal urine may be described as a transparent yellowish liquid with a characteristic odor. It is a complex watery solution of organic and inorganic substances. Most of the substances are waste products of body metabolism, or products derived from food. Even in health the composition varies, and under pathological conditions it may be further modified. For table showing composition of urine, consult summary.

Transparency. — The transparency of urine is relative and may be replaced by a marked turbidity, or the formation of sediments. On a vegetable diet the transparency is lessened, due to a precipitation of phosphates. If allowed to stand, normal urine develops a cloudy appearance due to the mucin secreted by the lining of the

[7] For discussion of habit training consult *Child Management,* D. A. Thom, M.D., Bureau Publication 143 of the Children's Bureau, U. S. Department of Labor, Washington, D. C., and *Enuresis as a Psychological Problem,* Helen T. Wooley, Ph.D., published by The National Committee for Mental Hygiene, 370 Seventh Avenue, New York.

urinary tract. In disease the urine may become clouded by the presence of pus.

Color. — The color of urine depends upon the quantity voided and the relative amounts of water and coloring matter. If the quantity is abnormally increased, it is usually more dilute and of a paler color; as, for instance, the copious light-colored urine of hysteria or diabetes insipidus. When the quantity is diminished, as in fevers, it is generally highly colored, because the amount of solids present is large. Other causes of change in color are the presence of foreign substances, such as sugar, bile, pus, much mucin, and large doses of certain drugs. In pernicious anemia, the erythrocytes are destroyed at an abnormally rapid rate, and pigment derived from these cells will be absorbed by the blood circulating in the liver, and later extracted in the kidneys, resulting in dark-colored urine.

Reaction. — The reaction is subject to wide variations depending upon the diet, but is usually on the acid side of neutral. The pH varies between 4.82 and 7.45. The acidity is increased by a high protein diet, acidosis, or when urine is concentrated, as in fevers; it is decreased by a vegetable diet. If human urine is allowed to stand for any length of time, it will become alkaline, due to the decomposition of urea and the production of ammonium carbonate. An odor of ammonia develops and a sediment may be deposited which has no pathological significance, although quacks and patent medicine advertisements may make it out to be a serious symptom.

Specific gravity. — In health the specific gravity may vary from 1.010 to 1.030, depending on the relative proportion of solid matter and water. When the solids are dissolved in a large amount of water, the specific gravity will naturally be lower than when the urine is more concentrated. The specific gravity is low in chronic nephritis and diabetes insipidus, high in fevers, and highest in diabetes mellitus, due to the presence of sugar.

Quantity. — The quantity of urine secreted in twenty-four hours varies. The normal average for a healthy adult is 1200 to 1500 cc. (40 to 50 oz.).

The quantity of urine may be increased by (1) the ingestion of a large amount of liquid, (2) checking of perspiration, (3) the action of diuretics, (4) nervousness, (5) certain diseases such as diabetes insipidus, diabetes mellitus, and hysteria.

From 6 months to 2 years	18–20 ounces.
From 2 to 5 years	16–26 ounces.
From 5 to 8 years	20–40 ounces.
From 8 to 14 years	32–48 ounces.

The quantity of urine may be decreased by (1) the ingestion of a small amount of liquid, (2) excessive loss of fluid from the body as by hemorrhage, vomiting, diarrhea, and high fever, (3) disease of the kidneys, and (4) the action of diaphoretics, muscular activity, or any treatment that induces free perspiration.

The amount of urine secreted by children in twenty-four hours is great in proportion to their body weight.

Water. — The water of the urine constitutes about 95 per cent of the fluid portion. The amount varies, due to the amount of water ingested, the amount lost through the skin, the lungs, and the alimentary canal.

Solids. — The solids of the urine consist of organic and inorganic substances. The amount varies and is influenced by diet, the activity of metabolism, age, body weight, exercise, and the ability of the kidneys to excrete. The average amount in twenty-four hours is about 60 grams. The chief *organic* substances are urea, creatinine, uric acid, and hippuric acid.

Urea ($CO(NH_2)_2$) constitutes about one-half (30 grams) of all the solids excreted in the urine. It is the principal waste product of the metabolism of the proteins of the foods and the tissues. In the liver, deaminization of proteins gives rise to ammonium carbonate. Under the action of the liver cells, ammonium carbonate is converted to urea. Normally about 0.028 per cent of urea is present in the blood and tissues. The kidneys constantly remove urea as it is formed, and by their activity keep the amount of urea in the blood at the low level given. If, for any reason, the kidneys fail to eliminate urea, the accumulation in the blood and tissues leads to a condition of poisoning.

The quantity of urea is increased by a diet rich in proteins, strenuous exercise, hot baths, fever in its early stages, and some diseases. A small amount of protein food, excessive vomiting, free perspiration, and diseases that interfere with elimination will decrease the amount of urea voided.

Creatine ($C_4H_9N_3O_2$) occurs in the muscles and blood, but normally is not present in the urine of adult man. It is constantly present in the urine of children; in women it is said to occur after menstruation, during pregnancy, and in the puerperium. Creatine is also present during fevers and starvation. By loss of water creatine becomes creatinine. Creatine exists in muscle as phosphocreatine. The energy for muscular contraction is obtained by the dissociation of creatine and phosphoric acid. During the relaxation period of the muscle, phosphocreatine is re-formed.

Creatinine ($C_4H_7N_3O$) occurs in the blood and in the urine constantly. Its relation to cellular metabolism is imperfectly known. Under normal conditions the amount of creatinine formed in the body is independent of the protein eaten. This has led some observers to think that it results from the metabolism of living tissue rather than from the metabolism of food protein. This lack of definite knowledge has led to two views. In one view, creatine and creatinine are related and creatine results from catabolism of living tissue. It is constantly produced, but is changed to creatinine before reaching the urine. Under such conditions as fever and starvation, the amount produced is too large to be wholly changed to creatinine, hence both creatine and creatinine appear in the urine. A second view is that the metabolism and significance of creatine and creatinine are different, *i.e.*, that creatine is constantly formed in the tissues, but is not converted to creatinine. In fact it is not regarded solely as a waste product prepared for excretion, but as a product which can be utilized under certain conditions for the reconstruction of the protein molecule. If not utilized, it may be excreted as creatine and creatinine.

Purine bodies. — For the formulæ of the *purine bodies* consult the summary. These bodies are related chemically and appear to have a common physiological significance. Uric acid ($C_5H_4N_4O_3$), the most highly oxidized of the purines, is the one found chiefly in the urine. Purines undergoing metabolism in the body may be derived from two sources: (1) the nucleoproteins of the tissues, described as endogenous, and (2) the nucleoproteins of the food, described as exogenous. The endogenous portion is relatively constant; the exogenous portion varies, depending on the kind and amount of food eaten. A diet lacking purine bodies (purine-free diet) reduces the amount of the exogenous purine bodies in the urine.

Hippuric acid ($C_9H_9NO_3$) is a constant constituent of human urine, averaging about 1 gm. daily. The quantity is increased on a vegetable diet and decreased on a flesh diet. It is thought that hippuric acid is a provision by which benzoic acid, when present in food or formed in the body, is conjugated with glycine and excreted.

Ammonia (NH_3) is formed constantly in the body, in the hydrolysis of the protein molecule, and in the process of deaminizing amino-acids. Most of the ammonia formed in this way is eliminated as urea, or it may be used to neutralize the acids formed in metabolism. The amount excreted daily averages about 0.7 gm.

Inorganic substances, such as sodium chloride[8] and the sulphates and phosphates of sodium, potassium, magnesium, and calcium, are found in the urine. The quantity of the salts depends upon the amount in the diet; *sodium chloride* is the one taken most freely, so it is the principal inorganic salt in the urine.

Abnormal constituents. — The chief abnormal constituents that are likely to appear in the urine are albumin, glucose, indican, acetone bodies, casts, calculi, pus, and blood.

Albumin. — Serum-albumin is a normal constituent of the blood, but usually the kidney cells do not allow it to pass into the tubules. Its presence in the urine is spoken of as albuminuria. Certain conditions favor albuminuria. These are: (1) increased blood-pressure in the renal vessels, (2) excessive amount of protein food in the diet, (3) nervous conditions, (4) irritation and abnormal conditions of the kidneys.

(1) Increased blood-pressure may be due to (*a*) stimulation of any part of the vasoconstrictor mechanism, (*b*) vigorous muscular exercise, (*c*) inelastic arteries due to arteriosclerosis, and (*d*) congestion of the kidneys because of interference with circulation through the renal vein. This interference may result from the pressure of tumors, or a pregnant uterus; or in diseases of the heart, liver, and lungs.

(2) After a meal unusually rich in proteins, albumin may be excreted in the urine. This is known as alimentary albuminuria, and both this and temporary albuminuria due to increased blood-pressure resulting from normal causes are known as functional albuminuria.

(3) Unstable nervous conditions such as exist (*a*) in children with neurotic tendencies, particularly during adolescence, and (*b*) in epileptics, favor the excretion of albumin.

(4) Irritation of the kidneys due to interference with circulation through the renal vein is likely to cause nephritis. In the treatment of poisoning by irritant drugs, and in infectious diseases, a liberal amount of water dilutes the irritating substances and lessens the danger of nephritis.

In abnormal conditions of the kidneys associated with albumin in the urine, there is usually retention of the inorganic salts and protein waste. In consequence some of the salts may pass from the blood into the tissues, and by raising the osmotic pressure promote excessive transudation of fluid into the tissues, thereby causing edema or dropsy. Retained protein waste is not poisonous, but it may undergo chemical changes which transform it into toxic substances and in this way cause the condition called uremia.

Glucose. — Normal urine contains so little sugar that for clinical purposes it may be considered absent. In health the amount of glucose present in the blood varies from 0.08 to 0.18 per cent. A higher per cent is irritating to the tissues, so when the quantity of sugar eaten is greater than the system can promptly change to glycogen and fat, the kidneys excrete it. When glucose is found in

[8] The excretion of chlorides is diminished in some forms of nephritis and fevers, especially pneumonia and inflammations, which lead to the formation of large exudates.

the urine from this cause, it is called *temporary glycosuria.* Frequent or continuous elimination of sugar shows that the body has not the usual power to oxidize sugar.

Indican. — Indican (potassium-indoxyl sulphate) is a potassium salt that is formed from indol. Indol results from the putrefaction of protein food in the large intestine. It is absorbed by the blood and carried to the liver, which it is thought changes the indol to indican, a less poisonous substance. Traces of indican are found in normal urine, but the presence of it in any amount is abnormal and denotes: (1) excessive putrefaction of protein food in the intestines, or (2) putrefaction in the body itself as in abscess formation. Excessive putrefaction may be due to a diseased condition of the intestine that interferes with absorption, to a diet containing too much protein food, or to constipation.

Acetone bodies. — When there is excessive consumption of fat, as in starvation of a fat animal, and in diabetes mellitus, in which sugar is not oxidized and the body lives on its fats and proteins, acetone bodies are formed. Under these conditions the oxidation of fats is not complete. Acetone bodies are found in the urine of normal individuals during periods of fasting and when the oxidation of fats is not carried to completion.

Casts. — In some abnormal conditions the kidney tubules become lined with substances which harden and form a mould or cast inside the tube. Later these casts are washed out by the urine, and their presence in urine can be detected by the aid of a microscope. They are named either from the substances composing them or from their appearance. Thus there are (1) pus casts, (2) blood casts, (3) epithelial casts from the walls of the tubes, (4) granular casts from cells which have decomposed and form masses of granules, (5) fatty casts from cells which have become fatty, and (6) hyaline casts which are formed from coagulable elements of the blood.

Calculi. — Mineral salts in the urine may precipitate and form calculi or stones. Calculi may be formed in any part of the urinary tract from the tubules to the external orifice of the urethra. The causes which lead to their formation are (1) an excessive amount of salts, (2) a decrease in the amount of water, and (3) abnormally acid or abnormally alkaline urine.

Pus. — In suppurative conditions of any of the urinary organs, pus cells are present in the urine.

Blood. — In cases of acute inflammation of any of the urinary organs, of tuberculosis, of cancer, and of renal stone, blood may be

found in the urine. If present in large quantity, the urine is deep red, and this condition is known as hematuria.

Toxicity of urine. — As urine is the medium by which the body gets rid of toxic material, it follows that urine itself is toxic, and must be eliminated, else a condition of toxemia will result. During illness the kidneys always try to eliminate any poisonous substances that find their way into the blood, whether these substances result from defective metabolism or from bacterial activity. This accounts for the fact that after a severe illness the kidneys are often left in a damaged condition, and suggests a copious intake of water in order to lessen the concentration of toxic materials, and thereby lessen the chances of injury to the tissues.

SUMMARY

- **Waste Products of body**
  - Carbon dioxide.
  - Water.
  - Organic and inorganic salts.
  - Hair, nails, dead skin.
  - Indigestible and undigested portions of food.
- **Wastes of cell metabolism**
  1. Soluble salts
     - Nitrogenous salts, *e.g.*, urea.
     - Inorganic salts, *e.g.*, sodium chloride.
  2. Liquid — water.
  3. Gas — carbon dioxide.
- **Excretory Organs**
  - Lungs.
  - Kidneys.
  - Alimentary Canal.
  - Skin.
- **Urinary System**
  - **Kidneys** (2) — secrete urine.
  - **Ureters** (2) — ducts which convey urine from kidneys to bladder.
  - **Bladder** (1) — reservoir for urine.
  - **Urethra** (1) — tube through which urine is voided.
- **Kidneys**
  - **Location**
    - Posterior part of lumbar region, behind peritoneum.
    - Placed on either side of spinal column and extend from upper border of twelfth thoracic to third lumbar vertebra.
  - **Capsule and support**
    - Imbedded in a mass of fatty tissue, adipose capsule.
    - Surrounded by fibrous tissue called renal fascia.
    - Held in place by renal fascia which blends with fasciæ on
      - quadratus lumborum,
      - psoas major, and
      - diaphragm.
    - Also by pressure and counter pressure of neighboring organs.

- **Kidneys**
  - **Size and shape**
    - About four and one-half inches long, two to three inches broad, and one inch thick.
    - Weight about four and one-half ounces (135 gm.).
    - Bean-shaped, tubular glands.
    - Concave border directed toward median line of body.
    - Hilum — fissure near center of concave side serves for vessels to enter and leave.
  - **Anatomy of the kidney**
    - **Pelvis** — upper expanded end of ureter.
    - **Calyces** — cup-like cavities of the pelvis that receive papillæ of pyramids.
    - **Cortex** — outer, more solid portion.
    - **Medulla** — inner, striated portion.
    - **Renal Columns** — interpyramidal extensions of cortical substance.
    - **Renal tubules**
      - Begin as glomerular capsules in the cortex of kidney, and after a very irregular course open into straight collecting tubes which pour their contents into calyces of pelvis.
    - **Pyramids**
      - Cone-shaped masses in the medullary portion of the kidney. Vary in number from eight to eighteen.
      - **Bases** directed toward cortex.
      - **Papillæ** — apices of the pyramids, directed toward pelvis.
      - Consist of renal tubules, blood-vessels, and lymphatics, held together by connective tissue.
    - **Renal corpuscles**
      - Minute tufts of capillaries — glomeruli — in cortical portion of kidneys which are surrounded by inverted capsule of renal tubule
    - **Blood-supply**
      - **Renal artery** — direct from aorta.
      - Before entering kidney divides into several branches.
      - **Arterial arches**
        - Lateral branches at the boundary zone between cortex and medulla.
        - 1. Send branches to cortex.
        - 2. Send branches to medulla.
      - **Venous arches**
        - Lateral branches at level of base of pyramids.
        - Receive blood from cortex.
        - Receive blood from medulla.
      - Veins empty into renal vein, leave kidney at hilus, and empty into inferior cava.
      - **Note** — Blood from renal artery serves for purposes of nourishment of kidney and purposes of excretion.
    - **Nerves**
      - Nerves derived from the renal plexus, and from the lesser and lowest splanchnic nerves.
      - Vasomotor, by regulating size of blood-vessels, influences blood-pressure.

- **Kidneys**
  - **Function**
    - **Secretion of urine depends upon**
      - Secretion of urine depends upon
        1. Capillary blood-pressure in glomeruli.
        2. Velocity of the blood flow through renal vessels.
        3. Activity of cells lining renal tubules.
      - Several theories proposed, one is as follows:
        1. Process of filtration. Water and dissolved substances are filtered from the blood during the circulation through the glomeruli.
        2. Probable reabsorption of some of the dissolved substances in the loop of Henle.
        3. Selective action of the cells lining the renal tubules. Urea and other dissolved substances are separated from the blood during the circulation through the plexus of capillaries which surrounds the tubules.

- **Ureters**
  - Excretory ducts. Connect kidneys with bladder and serve as passageway for urine.
  - Commence as calyces which surround renal papillæ. These join to form two or three short tubes and these unite to form renal pelvis.
  - Duct is size of goose-quill. 25–30 cm. long.
  - **Three coats**
    1. Mucous — lining.
    2. Muscular
       - Inner, longitudinal layer.
       - Outer, circular layer.
    3. Fibrous — carries blood-vessels and nerves.

- **Bladder**
  - Hollow muscular organ.
  - Situated in pelvic cavity behind the pubes
    - in front of rectum in male.
    - in front of anterior wall of vagina and neck of uterus in female.
  - Freely movable. Held in position by folds of peritoneum and fascia.
  - Size, shape, and position depend upon age, sex, and whether bladder is full or empty.
  - **Four coats**
    1. Mucous — lining.
    2. Areolar — connects mucous and muscular.
    3. Muscular
       - Inner layer — longitudinal.
       - Middle layer — circular
       - Outer layer — longitudinal.
    4. Serous — partial covering derived from peritoneum.
  - **Three openings**
    - Ureters open into lower part, about half an inch from median plane.
    - Urethral opening is below and in front of the opening of the ureters.
  - **Function**
    - Serves as a reservoir for the reception of urine.
    - When moderately distended, holds about 500 cc.

Urethra
- Membranous canal, extends from the bladder to the meatus urinarius.
- 3.8 cm. long in female, about 20 cm. long in male.
- In female behind symphysis pubis, and embedded in the anterior wall of vagina.
- Three coats
  1. Mucous — lining.
  2. Submucous — supports network of veins.
  3. Muscular
     - Inner — longitudinal.
     - External — circular.
- Meatus urinarius — external orifice located between clitoris and vagina.

Micturition
- Act of expelling urine from bladder.
- Occurs as result of irritation due to accumulation of urine in bladder.
- Reflex act — controlled by voluntary effort.

Retention
- Failure to void urine.
- Due to
  1. Some obstruction in urethra or neck of bladder.
  2. Nervous contraction of urethra.
  3. Dulling of the senses.
- May be accompanied by constant leakage, or involuntary voiding of small amounts.

Suppression or anuria — Failure of the kidneys to secrete urine.

Oliguria — Deficient secretion of urine.

Urine
- **Transparency** — is relative, depending on diet, etc.
- **Color** — depends on concentration. Relative amounts of water and solids.
- **Reaction** — usually acid side of neutral, average pH varies between 4.82 and 7.45.
- **Specific gravity** — average about 1.010 to 1.030. Depends on concentration.
- **Quantity**
  - Average 1200–1500 cc.
  - Increased by
    - Ingestion of large amount of fluid.
    - Checking of perspiration.
    - Action of diuretics.
    - Nervousness.
    - Diseases
      - Diabetes insipidus.
      - Diabetes mellitus.
      - Hysteria.
  - Decreased by
    - Ingestion of small amount of fluid.
    - Excessive loss of fluid from the body as by hemorrhage.
    - Vomiting, diarrhea.
    - High fever.
    - Disease of kidneys.
    - Increased action of skin.

- **Composition of Urine**
  - Water, 95 per cent.
  - Solids
    - **Organic** about 3.7 per cent
      - **Urea** $(CO(NH_2)_2)$ One-half of all the solids. About 30 gm. daily.
      - Creatine $(C_4H_9N_3O_2)$ and Creatinine $(C_4H_7N_3O)$.
      - Ammonia (NH_3).
      - Hippuric acid $(C_9H_9NO_3)$.
      - Purine bodies
        - Purine $(C_5H_4N_4)$
        - Adenine $(C_5H_3N_4NH_2)$
        - Guanine $(C_5H_3N_4ONH_2)$
        - Hypoxanthine $(C_5H_4N_4O)$
        - Xanthine $(C_5H_4N_4O_2)$
        - Uric acid $(C_5H_4N_4O_3)$
    - **Inorganic** about 1.3 per cent
      - Sodium chloride
      - Sulphates and Phosphates of
        - Sodium.
        - Potassium.
        - Magnesium.
        - Calcium.
        - Ammonia

- **Water**
  - Water lost from body through the kidneys, the skin, the lungs, and the alimentary canal.
  - Mainly by kidneys, water content of blood is constantly depleted.
  - Superfluous water ingested — eliminated by kidneys.

- **Urea** $CO(NH_2)_2$
  - Waste-product resulting from metabolism of proteins. Constitutes ½ of all the solids in urine, 30 gm.
  - About 0.028 per cent present normally in blood and tissues.
  - Increased by
    - Diet rich in proteins.
    - Strenuous exercise — hot baths.
    - Some diseases.
  - Decreased by
    - Small amount of protein food.
    - Excessive vomiting, free perspiration.
    - Diseases that interfere with elimination.

- **Creatine** $C_4H_9N_3O_2$
  - Occurs in blood in small amounts.
  - Normally not present in urine of adult man.
  - Constantly present in urine of children; in women after menstruation, during pregnancy, and puerperium.
  - **Two Views**
    1. Creatine — waste product of breakdown of living tissue, produced constantly and converted to creatinine before excretion.
    2. Metabolism and significance of creatine and creatinine differ. Creatine constantly formed as result of metabolism of tissues, but may be used for reconstruction of protein molecule. If not used, changed to creatinine and excreted.

- **Creatinine** $C_4H_7N_3O$
  - By loss of water creatine becomes creatinine. Is probably a waste product of the metabolism of protein tissue.

- **Hippuric Acid** $C_9H_9NO_3$
  - Constant constituent of urine.
  - Average about 1 gm. daily.
  - Increased on a vegetable diet.
  - Decreased on a flesh diet.

Ammonia NH_3
- Constant constituent of urine.
- Average amount 0.7 gm. daily.
- Amount increased in metabolic disturbances where oxidation is not complete.

Purine Bodies
- Purine ($C_5H_4N_4$)
- Adenine ($C_5H_3N_4NH_2$)
- Guanine ($C_5H_3N_4ONH_2$)
- Hypoxanthine ($C_5H_4N_4O$)
- Xanthine ($C_5H_4N_4O_2$)
- Uric acid ($C_5H_4N_4O_3$)
  - End-products resulting from metabolism of nucleoproteins of food (exogenous) and tissues (endogenous).
  - Purine-free diet reduces amount of exogenous purine bodies in the urine.

Salts
- Derived partly from food eaten, partly from metabolism of proteins, particularly neutralization of acids.
- Sodium chloride is most abundant.

Abnormal constituents
- Albumin.
- Glucose.
- Indican.
- Acetone.
- Casts.
- Calculi.
- Pus.
- Blood.

Albuminuria
- Albumin in urine.
- 1. Increased blood-pressure in renal arteries may be due to
  - (*a*) stimulation of the vasoconstrictor mechanism.
  - (*b*) vigorous muscular exercise.
  - (*c*) arteriosclerosis.
  - (*d*) congestion of the kidneys, due to pressure or diseases of heart, liver, and lungs.
- 2. Excessive amount of protein food.
- 3. Nervous conditions
  - Children of neurotic tendencies particularly during adolescence.
  - Epilepsy.
- 4. Irritation of kidneys — due to interference with venous return. Abnormal conditions such as nephritis — retention of organic salts and urea may result in edema or uremia.

Glycosuria
- Normal urine contains little sugar.
- **Temporary Glycosuria** — Follows ingestion of large amount of sugar, injury to head, or during convalescence from fevers.
- **Diabetes Mellitus** — Glucose persists in urine even when carbohydrate food is not eaten.

Indican
- Indican is potassium indoxyl sulphate.
- **Caused by**
  - Excessive putrefaction of proteins in intestines
    - due to interference with absorption.
    - due to excess of protein food.
    - due to constipation.
  - Putrefaction in body itself.

Acetone bodies — Result of incomplete oxidation of fats.

Casts
- Substances which harden and form a mould inside of tubules.
- Named from substances composing them or their appearance.
- Varieties
  - Pus casts, blood casts.
  - Epithelial casts, granular casts.
  - Fatty casts, hyaline casts.

Calculi
- Deposits of solid matter precipitated from the urine, vary in shape and size.
- **Causes**
  - Increase in slightly soluble constituents of urine.
  - Decrease in amount of water secreted.
  - Abnormally acid or abnormally alkaline urine.

Pus — Due to suppurative conditions of urinary organs.

Hematuria
- Blood in urine.
- Inflammation of urinary organs, tuberculosis, cancer, renal stone.

CHAPTER XXII

THE SKIN AND APPENDAGES. BODY HEAT; REGULATION OF HEAT. VARIATIONS IN TEMPERATURE

THE SKIN

The skin has many functions. It covers the body and (1) protects the deeper tissues from drying and injury; (2) it protects from invasion by foreign organisms; (3) it is an important factor in heat regulation; (4) it contains the end-organs of many of the sensory nerves; (5) it has limited excretory and absorbing powers. It will absorb oily materials placed in contact with it. Inunction of some substances in fats, as, for instance, mercury ointment, produces absorption. Cod liver oil is still sometimes rubbed into the skin of infants for nutritive purposes.

Structure. — It consists of two distinct layers:

(1) Epidermis, cuticle, or scarf skin. (2) Corium, cutis vera, or dermis.

Epidermis. — The epidermis is a stratified squamous epithelium, consisting of a number of layers of cells. It varies in thickness in different parts, being thickest on the palms of the hands and on the soles of the feet, where the skin is most exposed to friction, and thinnest on the ventral surface of the trunk, and the inner surfaces of the limbs. It forms a protective covering over every part of the true skin, and is closely moulded on the papillary layer of the corium. The external surface of the epidermis is marked by a network of ridges caused by the size and arrangement of the papillæ beneath. Some of these ridges are large and correspond to the folds produced by movements, *e.g.*, at the joints; others are fine and intersect at various angles, *e.g.*, upon the back of the hand. Upon the palmar surface of the fingers and hands, and the soles of the feet, the ridges serve to increase resistance between contact surfaces and therefore prevent slipping. On the tips of the fingers and thumbs these ridges form distinct patterns, which are peculiar to the individual and practically never change; hence the use of finger prints for purposes of identification.

From without inward four layers are named: (1) the **stratum corneum,** (2) the **stratum lucidum,** (3) the **stratum granulosum,** and (4) the **stratum mucosum.**

The three upper layers consist of cells, which are practically dead, and are constantly being shed and renewed from the cells of the stratum mucosum. In the stratum corneum the protoplasm of the cells has become changed into a protein substance called *keratin,* which acts as a waterproof covering, and prevents water from entering or leaving by the skin. The reaction is acid, and many kinds of organisms, when placed upon the skin, are destroyed, presumably from the effect of the acidity.

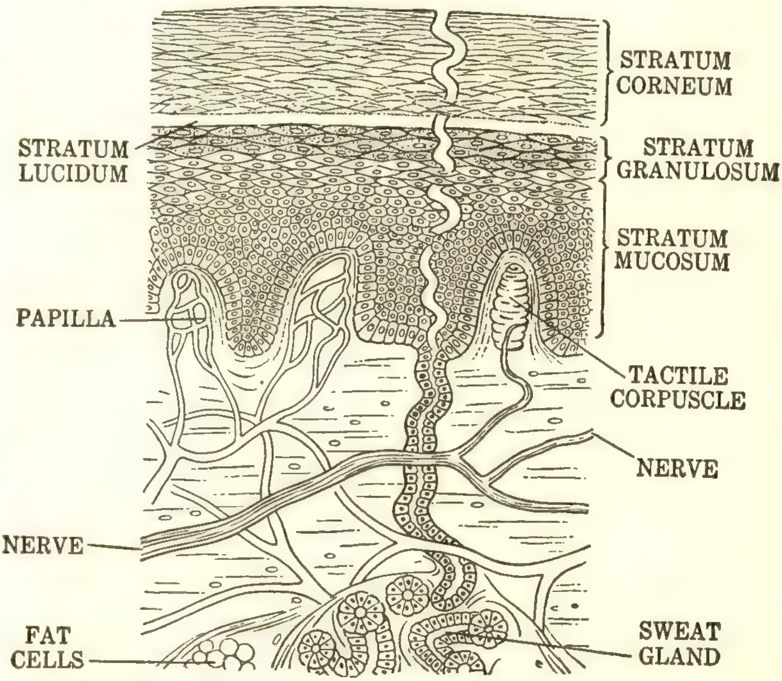


FIG. 236. — DIAGRAM OF A SECTION OF THE SKIN TO SHOW ITS STRUCTURE. The epidermis consists of the strata corneum, lucidum, granulosum, and mucosum. The corium lies below the epidermis.

The **stratum mucosum** consists of several layers of cells. The cells of the deepest layer are columnar in shape and are sometimes called the stratum germinativum. The growth of the epidermis takes place by multiplication of the cells of the germinative layer. As they multiply they push upward toward the surface those previously formed. In their upward progress these cells undergo

a chemical transformation, and the soft protoplasmic cells become converted into the flat scales which are constantly being rubbed off the surface of the skin. The pigment in the skin of the negro, as well as that of the nipple in white races, is found in the cells of the stratum mucosum. No blood-vessels pass into the epidermis; it, however, receives fine nerve fibers between the cells of the germinative layer.

Corium. — The corium is a highly sensitive and vascular layer of connective tissue. It contains numerous blood-vessels, lymph-vessels, nerves, glands, hair follicles, and papillæ, and is described as consisting of two layers: (1) **papillary or superficial layer,** (2) **reticular or deeper layer.**

(1) The surface of the **papillary** or **superficial** layer is increased by protrusions in the form of small conical elevations, called papillæ, whence this layer derives its name. They project up into the epidermis, which is moulded over them. The papillæ consist of small bundles of fibrillated tissue, the fibrils being arranged parallel to the long axis of the papillæ. Within this tissue is a loop of capillaries, and some papillæ, especially those of the palmar surface of the hands and fingers, contain *tactile corpuscles.*

The papillæ seem to exist chiefly for the purpose of giving the skin its sense of touch, being always well developed where the sense of touch is exquisite.

(2) The **reticular** or **deeper** layer consists of strong bands of white fibrous tissue and some fibers of yellow elastic tissue. These bands interlace and the tiny spaces left by their interlacement are occupied by adipose tissue and sweat glands. The reticular layer is attached to the parts beneath by a subcutaneous layer of areolar connective tissue, which, except in a few places, contains fat. In some parts, as on the front of the neck, the connection is loose and movable; in other parts, as on the palmar surface of the hands and the soles of the feet, the connection is close and firm. In youth the skin is both extensile and elastic, so that it can be stretched and wrinkled and return to its normal condition of smoothness. As age advances the elasticity is lessened, and the wrinkles tend to become permanent.

Blood-vessels and lymphatics. — The arteries which supply the skin form a network in the subcutaneous connective tissue and send branches to the papillæ, the hair follicles, and the sudoriferous glands. The capillaries of the skin are so numerous that when distended they are capable of holding a large proportion of the blood contained in the body. The amount of blood they contain

is dependent on their caliber, and this is regulated largely by the vasomotor nerve fibers.

There is a superficial and a deep network of lymphatics in the skin. These communicate with each other and with the lymphatics of the subcutaneous connective tissue.

Nerves. — The skin contains the peripheral terminations of many nerve fibers. These fibers may be classified as follows:

(1) Motor nerve fibers, including the vasoconstrictors and vasodilators distributed to the blood-vessels, and motor nerve fibers distributed to the arrector muscles (arrectores pilorum).

(2) Nerve fibers concerned with the temperature sense, which terminate in *cold receptors* and *receptors for warmth.*

(3) Nerve fibers concerned with touch and pressure, which terminate in *touch* and *pressure receptors.*

(4) Nerve fibers which are stimulated by pain. The number of *pain receptors* is estimated to be more than 2,000,000.

(5) Secretory nerve fibers which are distributed to the glands. Because of the number of sensory nerve fibers which lead from the skin to centers in the brain and spinal cord, nearly every nerve center in the body may be affected by sensations arising in the skin. It is for this reason that hydrotherapeutic applications, heat, cold, and counter-irritants excite so many and such varied reflexes.

THE APPENDAGES OF THE SKIN

The appendages of the skin are the nails, the hairs, the sebaceous glands, the sudoriferous or sweat-glands, and their ducts.

The Nails (Ungues). — The nails are composed of clear, horny cells of the epidermis, joined so as to form a solid, continuous plate upon the dorsal surface of the terminal phalanges. Each nail is convex on its outer surface, concave on its inner side, and closely adherent to the underlying corium, which is modified to form what is called the bed, or *matrix*, of the nail. At the hinder part of the bed of the nail the skin forms a deep fold, in which is lodged the root of the nail.

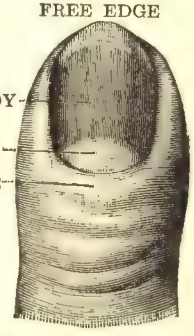


FIG. 237. — THUMB-NAIL. (Gerrish.)

The nails grow in length by multiplication of the soft cells in the stratum mucosum at the root. The cells are transformed into hard, dry scales, which unite to form a solid plate, and the nail, constantly receiving additions, slides

forward over its bed and projects beyond the end of the finger. When a nail is thrown off by suppuration or torn off by violence, a new one will grow in its place provided any of the cells of the stratum mucosum are left.

The hairs (pili). — The hairs are growths of the epidermis, developed in little pits, the hair follicles, which extend downward into the deeper part of the true skin, or even into the subcutaneous tissue. The hair grows from the bottom of the pit or follicle. The part which lies within the follicle is known as the root, and that portion which projects beyond the surface of the skin is called the shaft. The substance of the hair is composed of coalesced cells, arranged in different layers, and we usually distinguish three parts from without inward in the shaft of a hair:

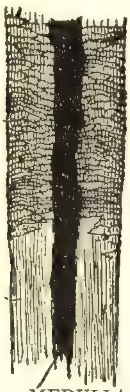


FIG. 238. — PIECE OF HUMAN HAIR. (Highly magnified.)

(1) *Cuticle,* — a single layer of delicate, scale-like cells, which overlap one another.

(2) *Cortex,* — a middle portion, which constitutes the chief part of the shaft. It is formed of elongated cells united to form flattened fibers, which contain pigment granules in dark hair and air in white hair.

(3) *Medulla,* — an inner layer composed of rows of many-sided cells, which frequently contain air spaces. The fine hairs covering the surface of the body and the hairs of the head do not have this layer.

The root of the hair is enlarged at the bottom of the follicle into a bulb. This bulb is composed of soft growing cells, and fits over a vascular papilla which projects into the bottom of the follicle. Hair has no blood-vessels but receives nourishment from the blood-vessels of the papilla.

Growth of hair. — Hair grows from the bottom of the follicle by multiplication of the soft cells (matrix cells) which cover the papilla. These cells become elongated to form the fibers of the fibrous portion, and as they are pushed to the surface, they become flattened and form the cuticle. If the scalp is thick, pliable, and moves freely over the skull, it is favorable to the growth of hair. A thin scalp that is drawn tightly over the skull tends to constrict the blood-vessels, lessen the supply of blood, and cause atrophy of the roots of the hair by pressure. In such cases massage of the head loosens the scalp, improves the circulation of the blood, and

usually stimulates the growth of the hair. The hairs are constantly falling out and constantly being replaced. In youth and early adult life not only may the discarded hairs be replaced, but there may be an actual increase of new hairs due to the development of new follicles containing matrix cells. When, from any cause, the matrix cells lose their vitality, new hairs will not develop.

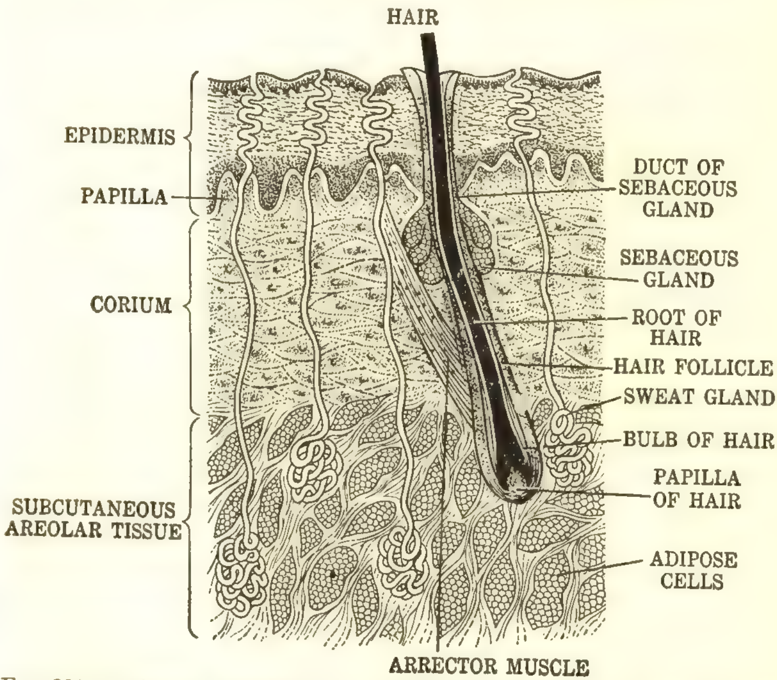


FIG. 239. — VERTICAL SECTION OF THE SKIN, SHOWING SEBACEOUS GLANDS, SWEAT-GLANDS, HAIR AND FOLLICLE, ALSO ARRECTOR MUSCLE. (Gerrish.)

With the exceptions of the palms of the hands, the soles of the feet, and the last phalanges of the fingers and toes, the whole skin is studded with hairs. The hair of the scalp is long and coarse, but most of the hair is very fine and extends only a little beyond the hair follicle.

Arrector (arrectores pilorum) muscles. — The follicles containing the hairs are narrow pits which slant obliquely upward, so that the hairs they contain lie slanting on the surface of the body. Connected with each follicle are small bundles of involuntary muscle fibers called the arrector muscles. They arise from the papillary layer of the corium and are inserted into the hair follicle below the entrance of the duct of a sebaceous gland. (See Fig.

239.) These muscles are placed on the side to which the hairs slope and when they contract, as they will under the influence of cold or terror, they straighten the follicles and elevate the hairs, producing the roughened condition of the skin known as "gooseflesh." As the sebaceous gland is situated in the angle between the hair follicle and the muscle, contraction of the muscle squeezes the sebaceous secretion out from the duct of the gland.

Sebaceous glands. — The sebaceous glands are compound alveolar glands lodged in the corium. They occur everywhere over the skin surface, with the exception of the palms of the hands and the soles of the feet. They are abundant in the scalp and face and are numerous around the apertures of the nose, mouth, external ears, and anus. Each gland consists of a single duct, which emerges from a cluster of alveoli. Each alveolus is composed of a basement membrane enclosing a number of epithelial cells. The alveolus is filled with larger cells containing fat. These cells are supposed to be cast off bodily, their detritus going to form the secretion. New cells are formed from the epithelial cells of the basement membrane. Occasionally the ducts open upon the surface of the skin, but more frequently they open into the hair follicles. In the latter case the secretion from the gland passes out to the skin along the hair. Their size is not regulated by the length of the hair.

Some of the largest are found on the nostrils and other parts of the face, where they may become enlarged with pent-up secretion. This retained secretion often becomes discolored, giving rise to the condition commonly known as blackheads. It also provides a medium for the growth of pus-producing organisms and consequently is a common source of pimples and boils.

Sebum. — The secretion of the sebaceous glands is called sebum. It contains fats, soaps, cholesterol, albuminous material, remnants of epithelial cells, and inorganic salts. It serves to protect the hairs from becoming too dry and brittle, as well as from becoming too easily saturated with moisture. Upon the surface of the skin it forms a thin protective layer, which serves to prevent undue absorption or evaporation of water from the skin. An accumulation of this sebaceous matter upon the skin of the fetus furnishes the thick, cheesy, oily substance called the *vernix caseosa.*

Sudoriferous or sweat-glands. — The sweat-glands are abundant over the whole skin, but they are largest and most numerous in the axillæ, the palms of the hands, soles of the feet, and the forehead. Each gland consists of a single tube, with the blind end coiled into a ball, which is lodged in the true skin or subcutaneous tissue. From the ball the tube is continued as the excretory duct of the

gland up through the corium and epidermis, and finally opens on the surface by a slightly widened orifice called a pore. Each tube is lined by a secreting epithelium continuous with the epidermis. The coiled end is closely invested by a meshwork of capillaries, and the blood in the capillaries is only separated from the cavity of the glandular tube by the thin membranes which form their respective walls. The secretory apparatus in the skin is somewhat similar to that which obtains in the kidneys; in the latter the blood-vessels are coiled up within the tube, while in the skin the tube is coiled up within the meshwork of blood-vessels.

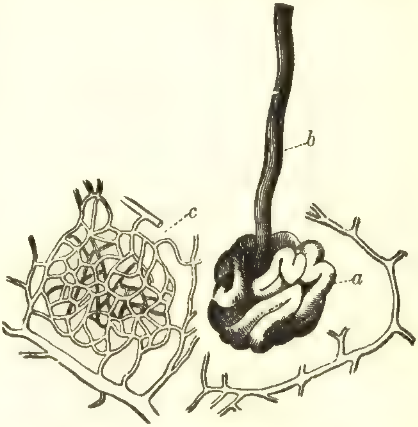


FIG. 240. — COILED END OF A SWEAT-GLAND. *a*, the coiled end; *b*, the duct; *c*, network of capillaries, inside which the sweat-gland lies.

Perspiration or sweat. — The reaction is usually acid, the average pH is 5.65. The sweat contains the same inorganic constituents as the blood, but in lower concentration. The chief salt is sodium chloride. The organic constituents are similar to those found in the urine, namely, urea, uric acid, creatinine, sulphates of phenol and skatol. Normally these are present in mere traces, but when sweating is profuse, the amount of urea eliminated may be considerable.

Quantity of perspiration or sweat. — Under ordinary circumstances, the perspiration that we are continually throwing off evaporates from the surface of the body without our becoming sensible of it, and is called *insensible perspiration.* When more sweat is poured upon the surface of the body than can be removed at once by evaporation, it appears on the skin in the form of drops, and we then speak of it as *sensible perspiration.*

The amount secreted during twenty-four hours varies greatly. It is estimated to average about 480–600 cc. (16 to 20 ounces) but it may be increased to such an extent that even more may be secreted in an hour. It is *increased* by: (1) increased temperature or humidity of the atmosphere; (2) a dilute condition of the blood; (3) exercise; (4) pain; (5) nausea; (6) mental excitement or nervousness; (7) dyspnea; (8) use of diaphoretics, *e.g.*, pilocarpine,

physostigmine, strychnine, nicotine, camphor, etc.; and (9) certain diseases, such as tuberculosis, acute rheumatism, and malaria.

The secretion of sweat is *decreased* by: (1) colds, (2) voiding of a large quantity of urine, (3) diarrhea, (4) certain drugs such as atropine and morphine in large doses, and (5) certain diseases, such as fevers, diabetes, and some cases of paralysis.

Activity of the sweat-glands. — Special secretory nerve fibers are supplied to the glandular epithelium of the sweat-glands. The activity of these glands is supposed to be the result either of direct stimulation of the nerve-endings in the glands, or indirect stimulation through the sensory fibers of the skin. The usual cause of profuse sweating is a high external temperature or muscular exercise. It is known that the high temperature acts upon the sensory cutaneous nerves, possibly the heat fibers, and stimulates the sweat fibers indirectly.

Functions of the sweat-glands. — While sweat is an excretion, its value lies not so much in the elimination of waste matter as in the loss of body heat by the evaporation of water. Each gram of water requires about 0.5 Calorie to cause it to evaporate, and this heat is taken from the body. This loss of heat helps to balance the production of heat that is constantly taking place. When the kidneys are not functioning properly, and the blood contains an excessive amount of waste matter, the sweat-glands will excrete some of the latter, particularly if their activity is stimulated. In the condition known as uremia when the kidneys secrete little or no urine, the percentage of urea in the sweat rises.

Ceruminous glands. — The skin lining the external auditory canal contains modified sweat-glands called *ceruminous* glands. They secrete a yellow, pasty substance resembling wax which is called cerumen.

BODY HEAT

From the standpoint of heat control animals may be divided into two great classes:

(1) **Constant temperature** (homoiothermous) animals, or those whose temperature remains practically constant whether the surrounding air is hotter or cooler than the body. Birds and mammals (including human beings) are in this class.

(2) **Variable temperature** (poikilothermous) animals, or those whose temperature varies with that of the surrounding medium, *e.g.*, snakes, frogs, fishes, etc. In winter their temperature is low, and in summer their temperature approximates that of their sur-

roundings, hence they are only cold-blooded in cold weather. The human fetus is in this class.[1]

The great difference between these two classes is in their reactions to external temperature. A cold environment reduces the temperature of the cold-blooded creature, reduces the metabolism of all its tissues, and thus reduces its heat production. The warm-blooded animal reacts in precisely the opposite way. Since his temperature remains constant, his heat production must increase in order to neutralize the effect of cold surroundings.

Production of heat. — The heat of the body is derived from food by a process of oxidation which reduces complex substances to simple ones, releasing energy in the form of heat, motion, secretory activity, etc. Since all the tissues of our body take part in the processes of oxidation, every cell may be described as a producer of heat. But tissues differ in their activities and in the quantity of heat they produce. The most important heat-generating organs are the skeletal muscles which are always in a state of tone and constitute about 50 per cent of the body weight. Next to these are the large glands. Minor sources of heat are friction, *i.e.*, that caused by the movements of the muscles, and the circulation of the blood; hot substances ingested; and radiation from the sun and heating appliances.

Distribution of heat. — The blood permeates all the tissues in a system of tubes or blood-vessels, and serves as an absorbing medium for the heat. Wherever oxidation takes place and heat is generated, the temperature of the blood circulating in these tissues is raised. Wherever, on the other hand, the blood-vessels are exposed to conditions which are cool because of heat lost by evaporation, etc., as in the moist membranes in the lungs, or the more or less moist skin, the temperature of the blood is lowered. But these changes are not effected instantaneously, and consequently the temperature of some internal parts must always be higher than that of others. This is particularly true of the liver because its metabolism is never at a standstill, and its blood-vessels are well protected against loss of heat. Because of this the temperature of the blood in different parts of the body varies slightly, but the circulation, now through warmer and again through cooler parts, tends to keep the average temperature at 37.8° C. (100° F.).

[1] At birth the heat-regulating mechanism is not "in working order," and infants are not able to regulate their body temperature, hence the importance of keeping them warm. Premature infants are even less able to regulate their body temperature, hence need of special means to keep them warm.

Loss of heat. — Heat is continually being produced in the body, and continually leaving the body by the skin and the lungs, and by the urine and feces which are at the temperature of the body when voided. It has been calculated that in every 100 parts about:

1792 Calories or 73.0 per cent is lost by conduction and radiation from the skin.
364 Calories or 14.5 per cent is lost by evaporation.
182 Calories or 7.2 per cent, vaporization of water, } 10.7 per cent is lost by
84 Calories or 3.5 per cent, warming of air, } expired air.
48 Calories or 1.8 per cent is lost by urine and feces.

From these figures it is evident that the skin is the important factor in getting rid of body heat. This is due: (1) to the large surface offered for radiation, conduction, and evaporation; (2) to the large amount of blood which constantly flows through it.

The temperature and humidity of the atmosphere may cause considerable difference in the percentages given above. A low temperature will increase the loss of heat by radiation, conduction, and convection and decrease that by evaporation. A high temperature will decrease the loss of heat by radiation and conduction and increase that by evaporation, owing to the greater production of sweat. Heat is lost by the evaporation of sweat, by the warming of air taken into the lungs, and by the evaporation of the water which leaves the body by the lungs. It requires about 0.5 Calorie to cause the evaporation of one gram of water, or about 250 Calories for the evaporation of 500 grams (one pint) of water. It is estimated that under ordinary circumstances it requires about 250 Calories daily to cause the evaporation of the sweat, and about 250 Calories to cause the evaporation of the water (about one pint) lost through the lungs. In hot weather the perspiration may be greatly increased, and more heat than usual be lost in this way, particularly if the humidity is not excessive. High humidity interferes with the evaporation of sweat, because air can take up only a certain amount of moisture. For this reason heat is more acutely felt when the humidity is high, even though the temperature is low, than when the humidity is low and the temperature high. Heat prostration and sunstroke are more likely to occur on hot days when the humidity is high than when it is low. A breeze favors evaporation, because it tends to drive away evaporated moisture, hence the comfort derived from an electric fan which keeps the air in motion.

THE REGULATION OF BODY HEAT

The temperature of the body is due to the maintenance of a certain balance between heat production (thermogenesis) and heat

loss (thermolysis). The body must control the production of heat and the loss of heat (thermotaxis). The part which the nervous system plays in this relationship is still an open question. The fact that infants cannot perform this function until some time after birth indicates that heat regulation follows a course parallel to the development of the nervous system. To many physiologists it has seemed reasonable to suppose that the *balance* between heat production and heat loss is controlled by a definite set of heat nerve fibers connected with a heat-regulating center in the brain. There is no convincing evidence of the existence of a definite set of heat nerve fibers, but much experimental evidence indicates the existence of a heat-regulating center in the brain. A conservative view is that the balance between heat production and heat loss is controlled by the activities of the structures listed, and these activities may be coördinated by a special heat-regulating center in the brain.

Heat Production (Chemical Regulation)	1. The quantity and character of food. 2. The motor nerve centers, and the motor nerve fibers to the skeletal muscles.
Heat Loss (Physical Regulation)	1. The respiratory center. 2. The sweat centers and sweat nerve fibers. 3. The vasomotor center and vasomotor nerve fibers. 4. The water-content of the blood.

Heat production (chemical regulation). — Heat production in the body is varied by increasing or decreasing the physiological oxidations. This end is effected in part voluntarily (1) by taking food and (2) by muscular exercise. In a previous chapter we described how the oxidation of different foodstuffs produces varying amounts of heat, and how the digestion products of foodstuffs, particularly proteins, stimulate the metabolism of the body and cause an increased amount of heat to be produced. In this connection the action of enzymes and some of the internal secretions, *e.g.*, thyroxin, is important. Thyroxin increases the oxidations of the body and stimulates all of the metabolic processes. During digestion heat is produced partly by the peristaltic action of the intestines and partly by the activity of the various digestive glands, particularly the liver. Cold weather stimulates the appetite, and an increased amount of food, usually accompanied by an increase of fats, increases heat production.

The motor nerve fibers which are distributed to the skeletal muscles are indirectly stimulated by cold. It causes the muscles to contract and speeds up the processes of oxidation. Muscular

contractions give rise to heat, therefore muscular activity is used as a means to counteract the effects of external cold. On the other hand, muscular activity does not increase the temperature in hot weather to any marked extent. This is accounted for by the fact that when muscular exertion causes the blood to circulate more quickly than usual, the blood-vessels in the skin dilate, the sweat-glands at the same time are excited to pour out more abundant secretion, and the heated blood passes in larger quantities through the cutaneous vessels which are kept well cooled by the evaporation of the perspiration; the general average temperature of the body is thus maintained.

Heat loss (physical regulation). — To a small extent our heat loss is controlled through an increase in the respiratory rate. The increased respirations associated with muscular activity aid somewhat in eliminating the excess of heat produced, although this factor is not as important as the sweating and flushing of the skin. In man respiration plays only a small part in heat regulation, but in animals that do not perspire, respiration is an important means of regulating the temperature.

During muscular activity or when the external temperature is high, the nerve-endings which respond to heat are stimulated, and these impulses are transmitted over sensory fibers to the nerve centers controlling the motor fibers of the sweat-glands. The motor fibers stimulate the activity of the sweat-glands, and an increased amount of sweat is poured out upon the surface of the body. An increased amount of heat is required to vaporize this sweat, and thus heat is lost. Excessive humidity interferes with the evaporation of water, and thus interferes with the loss of heat; hence the discomfort experienced on hot, humid days.

The sensory endings which are stimulated by heat not only transmit impulses that stimulate the sweat-glands to activity, but at the same time transmit impulses that result in the depression of the vasoconstrictor center leading to the arterioles of the skin. In consequence the arterioles dilate and more blood is sent to the surface to be cooled. When the external temperature is low, the sensory nerve-endings which are stimulated by cold transmit impulses which result in stimulation of the vasoconstrictors, and consequent contraction of the arterioles of the skin. This lessens the amount of blood in the skin arterioles, and lessens the amount of heat loss.

Recently it has been suggested that the concentration of the blood is a factor to be considered. The water of the body holds

heat, and when the external temperature is low, water is withdrawn from the blood to the tissues, and the blood is more concentrated. When the external temperature is high, water is withdrawn from the tissues to the blood. When the blood is dilute, an increased amount of water is brought to the surface and an increased loss of heat results, but when the water is withheld in the interior of the body, less heat is lost. Other factors to be considered are (1) size, (2) age, and (3) constitution.

Size. — The quantity of heat produced by well-nourished animals, including man, is relatively constant, but the larger the surface of the body exposed to a cooler medium, the greater must be the loss of heat, since the heat lost is related to the *area of surface.* Small animals present a proportionately larger surface to the surrounding medium than larger animals, hence the loss per unit of weight is greater, and this must be compensated for by a greater heat production.

Age. — In children the heat production is relatively large, because they are active and growing. Moreover, young children have not the constancy of temperature which is an evolved characteristic of adult life. On the contrary, they are subject to changes of body temperature which would be of grave import in an adult.

Constitution. — Individuals differ greatly in their power of heat loss. Apart from differences in size, and in the faculty of perspiration, there exist differences in compactness of shape, and in the amount of adipose tissue protecting the viscera.

Clothing. — By clothing we can aid the functions of the skin and the maintenance of heat; though, of course, clothes are not in themselves sources of heat. The kind of clothing to be worn should be determined by the necessity for diminishing the loss of heat as in cold weather, or facilitating this loss as in warm weather. Clothing of any kind captures a layer of warm and moist air between it and the skin, and thus diminishes greatly the loss by evaporation and radiation. In considering the heat value of clothing the important properties are: (1) whether it is loosely or tightly woven, (2) its thickness, and (3) its color.

(1) Materials that are loosely woven will be warmer than those that are tightly woven, because the meshes in a loosely woven material are capable of holding air, which is a poor conductor of heat, and thus prevents radiation. It is also true that two layers of thinner material are usually warmer than one layer of thicker material, because a layer of air is captured between the two.

(2) Thick material does not allow the warm air next the body to penetrate to the outside.

(3) Dark-colored materials absorb heat to some extent, hence they are warmer than light-colored textiles.

Thick, porous materials are used to keep the body warm. Wool has an additional advantage, as evaporation takes place more slowly from it than from linen, cotton, or silk, and it has a greater capacity for absorbing moisture, so that the layer of air next to the skin does not become saturated with moisture. Thin and very porous materials help to keep the body cool, because they allow the air to penetrate to the skin, and thus assist the evaporation of sweat.

Hot baths. — The primary effect of a hot bath is to prevent radiation of heat from the surface of the body, and some increase in temperature may result. If the bath is not continued for too long a time, this effect is counteracted by the increased perspiration that follows.

Cold or tonic baths. — The primary effect of a cold bath is similar to the effect of cold air. The cold contracts the arterioles of the skin, drives the blood to the interior, and increases oxidation. If the bath is a short one and is followed by friction (contrast condition, cold followed by heat), the reaction is for the arterioles to dilate, the heated blood is sent to the surface, the circulation is quickened, and there is a consequent loss of heat. In health the gain in heat is usually balanced by the loss of heat, and the purpose of a cold bath is to exercise the arterioles and stimulate the circulation. If the bath is continued for some time, the temperature of the skin, and of the muscles lying beneath, is reduced, and either the heat-producing processes may be checked and a loss of temperature result, or shivering may intervene. In this case the muscular contractions and constriction of the blood-vessels stimulate metabolism and heat production. When cold baths are given for the purpose of increasing heat elimination, friction is used during the bath to prevent shivering. Friction stimulates the sensory fibers of the skin, causes dilatation of the arterioles, and favors the flow of hot blood to the surface, thus decreasing the sensation of cold and increasing heat elimination. If properly given, cold baths stimulate the nervous system, improve the tone of the muscles, including the muscles of the heart and blood-vessels, stimulate the circulation, and favor the elimination of heat.

VARIATIONS IN TEMPERATURE

The temperature of the human body is usually measured by a thermometer placed in the mouth, axilla, or rectum. Such measurements show slight variations. The normal temperature by mouth is about 37° C. (98.6° F.), by axilla the temperature is lower, and by rectum it is usually one degree higher.

Normal variations. — Normal variations depend upon such factors as time of day, exercise, meals, age, sex, season, climate, and clothing. The temperature is usually lowest between 2 and 6 A.M., it rises slowly during the day, reaches its maximum between 5 and 7 P.M., and falls again during the night. This corresponds to the usual temperature ranges in fever, when the minimum is in the early morning, and the maximum is in the evening. Muscular activity and food cause a slight increase in temperature and probably account for the increase in temperature during the day. In the case of night workers who sleep during the day, the increase in temperature occurs during the night, which is the period when food is eaten and work performed. Age has some influence. Infants and young children have a slightly higher temperature (about 1°) than adults. Their heat-regulating mechanism is more easily disturbed and rise of temperature is caused by slight disturbances of digestion or metabolism and usually is less significant than the same increase in adults. Aged people show a tendency to revert to infantile conditions, and their temperature is usually slightly higher than in middle life. It is said that women have a slightly higher temperature than men. The effects of climate and clothing have been discussed.

Subnormal temperature. — In order to carry on the activities essential to life, the body must maintain a normal temperature. If the temperature falls much below normal, to about 35° C. (95° F.), life can be maintained for only a short time. Subnormal temperature may be due to excessive loss of heat, profuse sweating, hemorrhage, and lessened heat production, as in starvation. In cases of starvation the fall of temperature is very marked, especially during the last days of life. The diminished activity of the tissues first affects the central nervous system; the patient becomes languid and drowsy, and finally unconscious; the heart beats more and more feebly, the breath comes more and more slowly, and the sleep of unconsciousness passes insensibly into the sleep of death.

Abnormal variations. Fever. — The term *fever* is applied to an abnormal condition characterized by increased temperature, increased rate of heart action, increased respirations, increased tissue waste, faulty secretion, and various other symptoms such as thirst, weakness, and apathy. Some of the symptoms accompanying fever may be due to the substances or conditions causing the fever, and some to the high temperature, and some to both.

Cause. — The exact cause of fever is unknown. It may be due to diminished heat loss, increased heat production, or both. Fever is usually accompanied

by (1) increased catabolism of body tissue, as shown in the increased urea content of the urine, even though the dietary protein is not increased; in explanation of this it is suggested that the toxins which cause the fever produce some change in the cells which makes them susceptible to the action of oxidizing enzymes, so that oxidation and heat production are abnormally increased. Fever is accompanied also by (2) retention of water in the tissues resulting in a concentration of the blood. (3) Usually the superficial blood-vessels are contracted and this is thought to be caused by the toxins acting on the vasoconstrictor centers. It is believed that fever and the conditions that accompany it are protective reactions to overcome the effect of toxins on the body. The reasons for this are based on various laboratory experiments. Animals have been inoculated with bacteria or bacterial toxins, and then kept for a time at a temperature of about 40° C. (105° F.) with the result that they resisted the infection better than animals who were not subjected to this higher temperature. In connection with this, bacteriologists remind us that many organisms are killed at a temperature slightly above that of the body, and it may be that a high body temperature favors the formation of immune bodies. The contraction of the superficial blood-vessels sends more blood to the interior of the body, thus providing an increased number of phagocytes and antibodies to fight the infection.

SUMMARY

- **Skin**
  - **Functions**
    1. Covers the body.
    2. Protects the deeper tissues from
       - drying, injury,
       - invasion by foreign organisms.
    3. **Important** factor in heat regulation.
    4. Contains the end-organs of many sensory nerves.
    5. It has limited excretory and absorbing power.
  - **Consists of**
    - **Epidermis** is a stratified epithelium
      1. Stratum corneum
      2. Stratum lucidum
      3. Stratum granulosum
         - Practically dead cells being constantly shed and renewed from the stratum mucosum.
      4. Stratum mucosum
         - Soft protoplasmic cells that are constantly multiplying by cell division.
    - **Corium is a** layer of connective tissue
      1. Papillary layer — papillæ are minute conical elevations of the corium. They contain looped capillaries and some contain terminations of nerve fibers called tactile corpuscles.
      2. Reticular layer
         - Bands of white fibrous and yellow elastic tissue which interlace, leaving tiny spaces which are occupied by adipose tissue and sweat-glands.
  - **Blood-vessels** — The arteries form a network in the subcutaneous tissue and send branches to papillæ and glands of skin. Capable of holding a large proportion of total amount of blood in body.
  - **Lymphatics.** — There is a superficial and deep network of lymphatics in the skin.

Skin
- **Nerve fibers**
  1. Motor fibers to blood-vessels and arrector muscles.
  2. Fibers concerned with temperature sense.
  3. Fibers concerned with sense of touch and pressure.
  4. Fibers stimulated by pain.
  5. Secretory fibers which are distributed to the glands.
- **Appendages**
  - Nails.
  - Hairs.
  - Sebaceous glands.
  - Sudoriferous or sweat-glands.

Nails
- Consist of clear, horny cells of epidermis.
- Corium forms a bed or matrix for nail.
- Root of nail is lodged in a deep fold of the skin.
- Nails grow in length from soft cells in stratum mucosum at root.

Hairs (pili)
- The hairs grow from the roots.
- The roots are bulbs of soft, growing cells contained in the hair follicles.
- Hair follicles are little pits developed in the corium.
- Stems of hair extend beyond the surface of the skin, consist of three layers of cells: (1) cuticle, (2) cortex, and (3) medulla.
- Found all over body, except
  - Palms of the hands.
  - Soles of the feet.
  - Last phalanges of the fingers and toes.
- Arrector muscles are attached to corium and to each hair follicle. Contraction pulls hairs up straight, drags follicles upward, forces secretion of sebaceous glands to surface, and forces blood to interior.

Sebaceous glands
- Compound alveolar glands, the ducts of which usually open into a hair follicle, but may discharge separately on the surface of the skin.
- Lie between arrector muscles and hairs.
- Found over entire skin surface except
  - palms of hands.
  - soles of feet.
- Secrete *sebum*, a fatty, oily substance, which keeps the hair from becoming too dry and brittle, the skin flexible, forms a protective layer on surface of skin, and prevents undue absorption or evaporation of water from the skin.

Sweat-glands
- Tubular glands, consist of single tubes with the blind ends coiled in balls, lodged in subcutaneous tissue, and surrounded by a capillary plexus. Secrete sweat and discharge it by means of ducts which open exteriorly.

Sweat
- Watery, colorless, turbid liquid, salty taste, distinctive odor, and usually an acid reaction, pH is 5.65.
- Contains the same inorganic constituents as the blood, but in lower concentration.
- Average quantity, about 16 to 20 ounces in twenty-four hours

Sweat

- Amount increased by
  1. Increased temperature or humidity of the atmosphere.
  2. Dilute condition of blood.
  3. Exercise.
  4. Pain.
  5. Nausea.
  6. Mental excitement or nervousness.
  7. Dyspnea.
  8. Use of diaphoretics, *e.g.*, pilocarpine, physostigmine, strychnine, nicotine, camphor.
  9. Various diseases, such as tuberculosis, acute rheumatism, and malaria.
- Amount decreased by
  1. Cold.
  2. Voiding a large quantity of urine.
  3. Diarrhea.
  4. Certain drugs, *e.g.*, atropine and morphine in large quantities.
  5. Certain diseases
     - Fevers.
     - Diabetes.
     - Some paralyses.

Activity of sweat-glands due to

1. Direct stimulation of nerve-ending in sweat-glands.
2. Indirect stimulation through sensory nerves of the skin.
3. Influenced by external heat, dyspnea, muscular exercise, strong emotions, and the action of various drugs.

Function

- Importance *not* in elimination of waste substances in perspiration, but because of **heat** needed to cause evaporation of perspiration.
- When kidneys are not functioning properly, sweat-glands will excrete waste substances, particularly if stimulated.

Ceruminous glands

- Modified sweat-glands.
- Found in skin of external auditory canal.
- Secrete cerumen, a yellow, pasty substance, like wax.

Body heat

- Animals divided into 2 classes
  1. Homoiothermous or those which have an almost constant temperature. Birds and mammals (including human beings) are in this class.
  2. Poikilothermous or those whose temperature varies with that of their environment, *e.g.*, snakes, frogs, and fishes. The human fetus is in this class.
- Derived from
  1. Food by a process of **oxidation** which reduces complex substances to simple ones. Every body cell produces heat, but the most important heat-producing organs are the muscles.
  2. Minor sources
     - Friction of muscles, blood, etc.
     - Hot substances ingested.
     - Radiation from sun and heat-appliances.
- **Distributed** — by the blood circulating through the blood-vessels.

- **Body heat**
  - **Lost by**
    - Skin — 2156 calories or 87.5 per cent
      - Offers large surface for radiation, conduction, and evaporation of sweat.
      - Contains large amount of blood.
    - Lungs — 276 calories or 10.7 per cent is lost warming the expired air and the evaporation of the water of respiration.
    - Urine and feces — 48 calories or 1.8 per cent is lost warming the urine and feces.

- **Regulation of body heat**
  - Due to maintenance of *balance* between heat production and heat dissipation.
  - **Heat Production**
    - By physiological oxidations, due to
      - Food.
      - Muscular exercise.
  - **Heat Loss**
    1. The respiratory center.
    2. The sweat center and sweat nerves.
    3. The vasomotor center and nerves.
    4. The water content of the blood.
  - Coördinated by heat-regulating center in the brain.
  - **Other factors**
    1. Size.
    2. Age.
    3. Constitution.
  - **Aided by**
    - (*a*) Use of suitable clothing.
    - (*b*) Use of hot and cold baths.

- **Variations in temperature**
  - The normal temperature by mouth is about 37° C (98.6° F).
  - **Normal**
    1. Depends on where temperature is taken
       - Mouth.
       - Axilla.
       - Rectum.
    2. Depends on time of day
       - Lowest in early morning, between 2 and 6 A.M.
       - Highest in early evening, between 5 and 6 P.M.
    3. Slightly increased by muscular activity and the digestive processes.
    4. Age. Higher and more variable in
       - Infants, children, and the aged.
    5. Sex.
    6. Season.
    7. Climate.
    8. Clothing.
  - **Subnormal due to**
    - Excessive loss of heat.
    - Profuse sweating and hemorrhage.
    - Lessened heat production as in starvation.
  - **Abnormal**
    - **Fever**
      - **Symptoms**
        - Increased temperature.
        - Increased pulse.
        - Increased respirations.
        - Increased tissue waste.
        - Faulty secretion.
        - Various other symptoms such as thirst, weakness, and apathy.
      - **Cause** — not definitely known.
      - **Value** — may be a protective reaction.

CHAPTER XXIII

SENSE ORGANS; TASTE, SMELL, HEARING, AND SIGHT

The sensory nerve fibers which have been discussed in Chapter VIII have their peripheral endings in receptors or sensory end-organs. These receptors receive stimuli, transform these stimuli to nerve impulses, and pass the nerve impulses on to the nerve fibers, which carry them to centers in the central nervous system for interpretation or for linkage by means of synapses with other sensory and motor fibers for interpretation and control.

Sensory Unit. — Under the term *sensory unit*, we include (1) a peripheral end-organ or receptor, (2) the sensory path through which the impulses are conveyed, and (3) a center in the cortex, which interprets the sensation. It is through the agency of the sensory units that we derive information about ourselves, and the world in which we live. The limitations of the sense organs restrict our knowledge of the many transformations of energy that are going on around us, except as we are able to devise means of extending them artificially. Thus our knowledge of the microscopic forms of life depends upon the extension of our sight by means of magnifying lenses. Wireless waves circulated through the ether unknown to us until our sense of hearing was extended by the use of sound amplifying devices.

Sensations. — Sensations are the conscious results of processes which take place within the brain, in consequence of impulses derived from receptors. Many sensations are not followed by motor reactions, but are stored as memory concepts, and may be called into play at any time, without an external stimulus. The sensitiveness of the numerous receptors to stimulation varies. In some parts of the body the slightest pressure will arouse a sensation while a similar degree of pressure in another part may fail to produce any sensation at all. The minimal stimulus necessary to arouse a sensation in any receptor is described as the *threshold* stimulus for that organ.

Sensations are felt and interpreted in the brain. Our habit of projecting sensations to the part that is stimulated tends to obscure this fact. In reality we see and hear with our brains, because the eye and ear serve only as end-organs to receive the

stimulus which must be carried to the brain and interpreted before we do see or hear.

Classification. — Formerly it was customary to classify the senses in two groups, *i.e.*, special and common. The special included the so-called five senses of man, namely, sight, hearing, touch, taste, and smell. All others were grouped as general.

Another classification is based on the part of the body to which the sensation is projected. All of our sensations are aroused in the brain, and the changes which result in consciousness occur there. But we project the sensation either to the exterior of the body or to some peripheral organ in the body. On this basis, sensations may be classified as external or exterior, and internal or interior. The external are those in which the sensations are projected to the exterior of the body, namely sight, hearing, taste, smell, pressure, and temperature (heat and cold). The internal are those in which the sensations are projected to the interior of the body, and include pain, muscle sense, sensations from the semicircular canals and vestibule of the internal ear, hunger, thirst, sexual sense, fatigue, and other less definite sensations from the viscera. Classification on this basis is not always satisfactory, because our mental projections are not always the same.

Instead of classifying the sensations, the *receptors* may be classified as (1) exteroceptors, stimulated by forces outside of the body; (2) proprioceptors, stimulated by activities that occur in connection with muscles and articulations; and (3) interoceptors, stimulated by substances or conditions within the viscera.

Another classification of the receptors is based upon the kind of stimuli to which they are sensitive. This classification lists (1) chemo-receptors, such as those of smell and taste, which are excited by suitable concentrations of substances in solution; (2) mechanico-receptors, such as those for sound, for pressure on the skin (touch), and receptors which are stimulated by mechanical pressure; and (3) radio-receptors, such as those for light, heat, and cold, which are excited by radiant energy. According to this classification, it is difficult to place the receptors for pain. Some receptors have not been identified anatomically, *e.g.*, receptors for the senses of hunger, appetite, thirst, etc., consequently, they cannot be classified satisfactorily.

Cutaneous sensation. — The sensory nerves of the skin mediate different qualities of sensation, *i.e.*, pressure, cold, heat, and pain. The surface of the skin is a mosaic of tiny sensory spots separated by relatively wide intervals. Each spot coincides with

the location of some special end-organ and serves a specific sense. These various spots are placed either singly or in clusters. In some locations one variety predominates, in others another. It is a matter of common knowledge that the sensitiveness of these varieties of cutaneous sensation differs in different parts of the body, *e.g.*, the tip of the finger is more sensitive to pressure or contact than to alterations of temperature. The hot and cold spots and the pressure points can be located by passing a metallic point slowly over the skin. At certain points a feeling of contact or pressure will be experienced, and at other points a feeling of

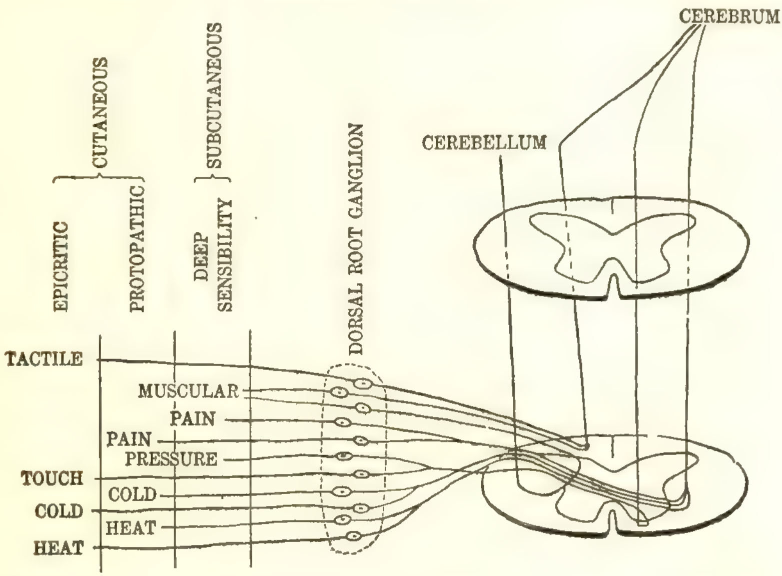


FIG. 241. — DIAGRAM OF COURSE OF CUTANEOUS FIBERS ON REACHING THE CORD.

cold or heat, depending on whether the temperature of the instrument is higher or lower than that of the skin.

It is estimated that, for the whole cutaneous surface, there are something like 3,000,000 to 4,000,000 pain points, 500,000 pressure points, 150,000 cold points, and about 16,000 warm points.[1]

Classification of cutaneous sensations. — Some authorities suggest that the cutaneous senses be classified on the basis of the loss of sensation after division of the cutaneous nerves and the subsequent, gradual, and separate return of these sensations, after suture of the divided ends. It has been found that the skin

[1] *Text-Book of Physiology*, W. H. Howell.

is supplied with two sets of nerve fibers which regenerate at different times and these are named respectively protopathic and epicritic. The *protopathic* group comprises three qualities of sensation, *i.e.*, (1) pain, (2) heat above 37° C. (98.6° F.), and (3) cold below 26° C. (78.8° F.). This system conveys sensations of pain and of extreme changes of temperature, but the sensibility is low and the localization poor. It is found in the viscera and from a functional standpoint may be considered as a defensive agency toward pathologic changes. The *epicritic* group contains separate fibers for heat, cold, light pressures, and tactile discriminations which give us sensations of (1) light touch and (2) small differences of temperature between 26° C. (78.8° F.) and 37° C. (98.6° F.), *i.e.*, the range of temperature to which the temperature nerves of the protopathic system are insensitive. It is through the sensations mediated by these fibers that we recognize the size and shape of objects. The epicritic group constitutes the special characteristic of the skin area and is not found in other organs.

In addition to the protopathic fibers the deeper tissues are supplied with fibers which give us a sense of pressure, and in the case of the muscles and joints, with fibers which give us a knowledge of the position of the movable parts of the body. The paths which these various fibers take in their journey through the central nervous system may be studied in Fig. 241.

Pain. — Excessive stimulation of any of the sense organs may give rise to unpleasant sensations, but it is thought that actual pain is caused by the stimulation of pain receptors. They are most abundant in superficial parts of the body, which are most exposed to injury. The meninges of the brain are sensitive to injury, but the brain itself is insensitive to pain. The deeper viscera of the thorax and abdomen are insensitive to mechanical, chemical, or thermal stimuli, though they are sensitive to pain arising from internal disorders (colic). If other receptors are stimulated simultaneously with those of pain, the sensation is modified, usually augmented, *e.g.*, a burn causes stimulation of the hot spots and the pain receptors, hence the resulting pain is interpreted as burning. Pain acts as a danger signal by means of which abnormal processes may be detected. In many cases it compels rest and thereby favors the healing of a diseased part.

Referred pains. — Normally we are able to localize pain arising in the skin, accurately. On the contrary, pain arising in the internal organs is often located very inaccurately. For example, the pain from a severe toothache may be projected quite diffusely

to the side of the face. An interesting fact in this connection is that such pains are often referred to points on the skin and may be accompanied by skin areas of tenderness. Pains of this kind are spoken of as referred pains. It has been shown that the different visceral organs have a more or less definite relation to certain areas of the skin. Pains arising from stimuli acting upon

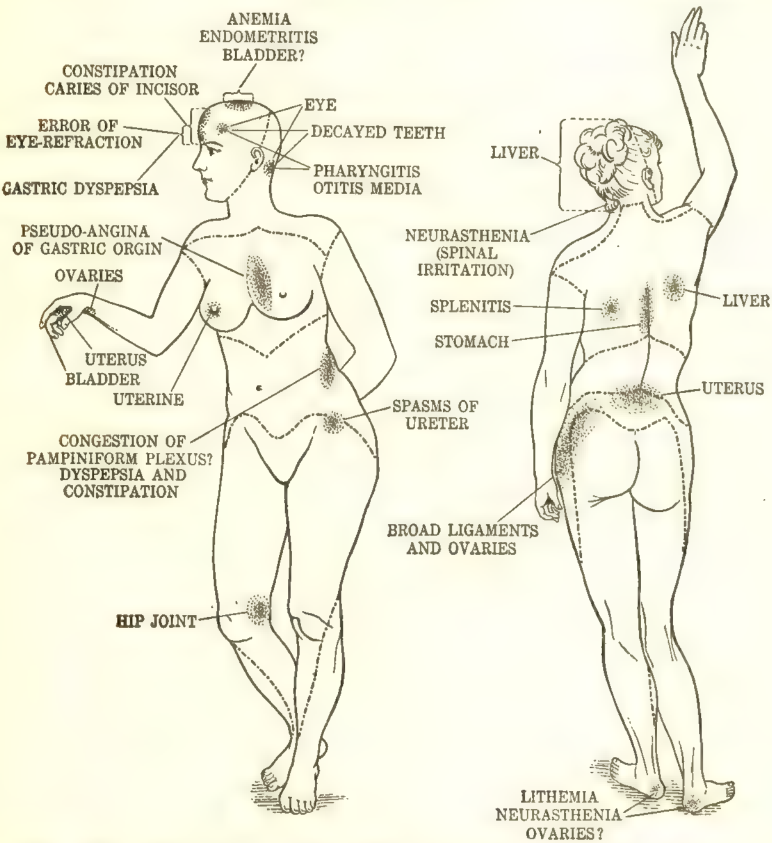


Fig. 242. — Cutaneous Areas Which Are the Seat of Referred Pain. (*Rational Hydrotherapy*, Courtesy of Modern Medicine Publishing Co.)

the intestines are located in the skin of the back, loins, and abdomen, in the area supplied by the ninth, tenth, and eleventh dorsal spinal nerves. Pains from irritations in the stomach are located in the skin over the ensiform cartilage, those from the heart in the scapular region. The explanation of this misreference is that the pain is referred to the skin region that is supplied from the spinal

segment from which the organ in question receives its sensory fibers, the misreference being due to a diffusion in the nerve centers. (See Fig. 242.) Examples of referred pain are (1) in appendicitis the abdominal pains are often remote from the usual position of the appendix; (2) in some pneumonia cases abdominal pain is the prominent symptom; (3) in angina pectoris the pain radiates to the left shoulder and down the arm, etc.

Muscular or deep sensibility. — There are special sensory end-organs in the muscles, the so-called *muscle spindles*, and in the attached tendons the *tendon spindles* or *tendon organs of Golgi*. From these end-organs afferent fibers carry impulses to centers in the brain, which send out impulses along efferent fibers to the muscles. There is thus a circle of nerve fibers between the brain and the muscles, one fiber giving the sense of the condition of the muscle to the brain, and another carrying the impulse from the brain to the muscle. This gives us a certain consciousness of the condition of our muscles at all times, and enables us to coördinate the contractions of harmonious groups in order to produce voluntary movements.

Hunger. — The feeling that we commonly designate as hunger occurs normally at a certain time after meals and is usually projected to the region of the stomach. It is presumably due to contractions of the empty stomach, which stimulate the fibers distributed to the mucous membrane. If food is not taken, hunger increases in intensity for a time and is likely to cause fatigue and headache. Professional fasters state that after a few days the pangs of hunger diminish and sometimes disappear. In illness hunger contractions may not occur at all, even when the food taken is not sufficient. Probably this results from a lack of muscular tone in the stomach. On the other hand, hunger contractions may be frequent and severe even if an abundance of food is taken regularly as in diabetes. This indicates malnutrition.

Appetite. — Some authorities class appetite as a mild form of hunger. Others consider that hunger and appetite constitute two different sensations mediated by two different physiological mechanisms. The sensory apparatus for hunger lies in the walls of the stomach, probably in the muscular coats, and is stimulated by the contractions of the musculature. The sensations aroused are more or less disagreeable. Appetite, on the contrary, is an entirely pleasant sensation aroused in part through the sensory nerves of taste and smell, and associated with previous experiences.

Thirst. — This sensation is projected to the pharynx, and the facts that are known seem to indicate that the sensory fibers of this region have the important function of mediating this sense. Our normal thirst sensations are designated as pharyngeal thirst to indicate the probable origin of the sensory stimuli. Local drying in this region, from dry or salty food, or dry and dusty air, produces a sensation of thirst that may be appeased by moistening the membrane with a small amount of water not in itself sufficient to relieve a genuine water need of the body. Prolonged deprivation of water affects the water content of all the tissues and gives rise to sensations not of simple thirst alone, but of actual pain and suffering. Under these conditions it is probable that sensory fibers are stimulated in many tissues, and in addition the metabolism of the nervous system is directly affected by loss of water.

Nausea. — This sensation may be due to stimulation from the stomach, to substances in the blood, and to impulses coming from various parts of the body, *e.g.*, the organs of sight, taste, and smell.

TASTE

In addition to the proper organs for receiving, communicating, and perceiving the sensory impulse, there must be present a savory substance which must be in solution. The solution in the case of dry substances is effected by saliva. It is also necessary that the surface of the organs of taste shall be moist. The substances which excite the special sensation of *taste* act by producing a change in the taste-buds and this change furnishes the required stimulus.

Taste-buds. — They are ovoid bodies, with an external layer of supporting cells, and contain in the interior a number of elongated cells, which end in hair-like processes that project through the central taste pore. These cells are the sense cells, and the hair-like processes probably are the parts stimulated by the savory substances. The taste-buds are found chiefly on the surface of the tongue, though some are scattered over the soft palate, fauces, and epiglottis.

The tongue. — The tongue is a freely movable muscular organ consisting of two distinct halves united in the center. The root of the tongue is directed backward and is attached to the hyoid bone by several muscles. It is connected with the epiglottis by three folds of mucous membrane, and with the soft palate by means of the glossopalatine arches.

Papillæ of the tongue. — The tongue is covered with mucous membrane. The mucous membrane on the under surface is similar to that lining the rest of the mouth, but the mucous membrane on the upper surface is studded with papillæ. The papillæ are projections of connective tissue, covered with stratified squamous epithelium, and contain a loop of capillaries among which nerve fibers are distributed. They give the tongue its characteristic rough appearance. Of these papillæ there are four varieties:

(1) Vallate (circumvallate) papillæ are the largest, are circular in shape, and form a V-shaped row near the root of the tongue

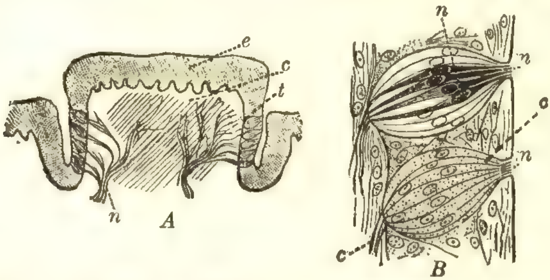


FIG. 243. — *A*, a vallate papilla cut lengthwise; *c*, corium; *e*, epidermis; *n*, nerve-fibers; *t*, taste-buds. *B*, the two taste-buds at *t* more highly magnified, the lower as seen from the outside showing *c*, the outer or supporting cells; the upper as seen in section showing *n*, four inner cells with processes *m*, projecting at the mouth of the bud.

with the open angle of the V turned toward the lips. They serve to secrete mucin and contain *taste-buds.*

(2) Fungiform papillæ are the next in size, and are so named because they resemble fungi in shape. They are found principally on the tip and sides of the tongue.

(3) Filiform papillæ cover the anterior two-thirds of the dorsum of the tongue and bear on their free surface delicate brush-like processes which seem to be specially connected with the sense of touch, which is very highly developed on the tip of the tongue.

(4) Simple papillæ similar to those of the skin cover the larger papillæ and the whole of the mucous membrane of the dorsum of the tongue.

Nerve supply of the tongue. — The nerve fibers which terminate in the taste-buds are: (1) filaments of the lingual nerve, which is a branch of the fifth or trigeminal, (2) filaments of the chorda tympani, a branch of the seventh or facial, and (3) filaments of the ninth or glossopharyngeal nerve.[2] The twelfth or hypoglossal nerve is

[2] This is a generally accepted view, but other statements may be found in various textbooks.

distributed to the tongue, but is a motor nerve and is not concerned in the sense of taste or touch.

The sense of touch is very highly developed here, and with it the sense of temperature, pain, etc. Upon these tactile and muscular senses depends, to a great extent, the accuracy of the tongue in many of its important uses — speech, mastication, deglutition, sucking.

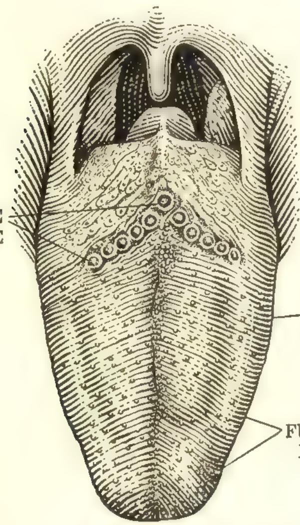


FIG. 244. — THE UPPER SURFACE OF THE TONGUE.

Classification of taste sensations. — Our taste sensations are very numerous, but four fundamental or primary sensations are recognized, namely — salty, bitter, acid, and sweet. All other sensations are combinations of these, or combinations of one or more of them with sensations of odor, or with sensations derived from stimulation of other nerves in the tongue. The seemingly great variety of our taste sensations is due to the fact that we confuse them or combine them with simultaneous odor sensations. Thus the flavors in fruits are designated as tastes because they are experienced at the same time these objects are eaten. If we shut off the nasal cavities as by holding the nose, the so-called taste often disappears in large measure. Very disagreeable tastes are usually due to unpleasant odor sensations. Hence the practice of holding the nose when we wish to swallow a nauseous dose. On the other hand, some volatile substances which enter the mouth through the nostrils and stimulate the taste-buds are interpreted by us as odors. The odor of chloroform is largely due to stimulation of the sweet taste in the tongue.

SMELL

The first essentials are a special nerve and nerve center, the changes in whose condition are perceived as sensations of odor. The special organs for this sense must be in their normal condition,

and a stimulus (odoriferous substance) must be present to excite them.

Olfactory nerves. — The olfactory nerves are the special nerves of the sense of smell, and are spread out in a fine network over the surface of the superior nasal conchæ and the upper third of the septum. These nerves end in special organs known as olfactory cells, which lie among supporting epithelial cells of a columnar shape. Each cell bears on its free end a tuft of six to eight hair-like processes. At the free edge of the cells there is a limiting membrane through which the olfactory hairs project. The basal

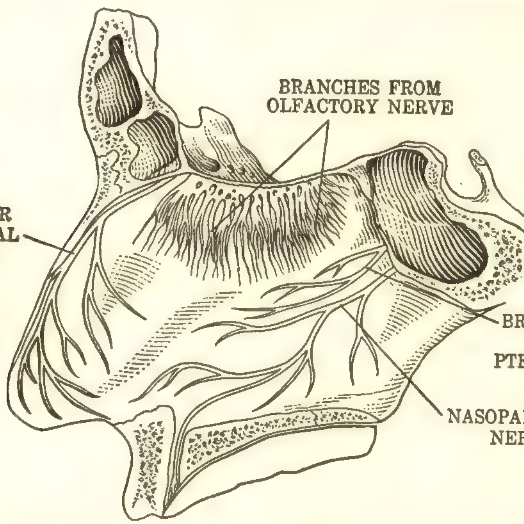


FIG. 245. — THE NERVES OF THE LEFT SIDE OF THE SEPTUM OF THE NOSE.

ends of the olfactory cells are prolonged as nerve fibers, which pierce the cribriform plate of the ethmoid bone and end in a mass of gray matter called the olfactory bulb. In the olfactory bulb these fibers form synapses with the dendrites of the so-called mitral cells. Through the axons of the mitral cells impulses are conducted to their various terminations in the olfactory lobe, either of the same or the opposite side.

The nerve fibers which ramify over the lower part of the lining membrane of the nasal cavity are branches of the fifth or trigeminal nerve. These fibers furnish the tactile sense and enable us to perceive, by the nose, the sensations of cold, heat, tickling, pain, and tension or pressure. It is these nerve fibers which are affected by strong irritants, such as ammonia or pepper.

Odoriferous bodies emit particles which usually are in gaseous form. These particles must penetrate into the upper part of the nasal chamber, and, after solution in the moisture of the lining membrane, act chemically upon the sensitive hairs of the olfactory cells, which transmit impulses to the olfactory lobe and give rise to the sensation of smell.

If we wish to smell anything particularly well, we sniff the air up into the higher nasal chambers, and thus bring the odoriferous particles more closely into contact with the olfactory hairs. Odors can also reach the nose by way of the mouth. Many flavors of food are really odors rather than gustatory sensations and we become aware of them just after swallowing. During swallowing the posterior nares are closed by the soft palate, which then opens, permitting odoriferous molecules to reach the sensory epithelium of the nose, through the wide posterior nares.

Each substance we smell causes its own particular sensation, and we are not only able to recognize a multitude of distinct odors, but also to distinguish individual odors in a mixed smell. These odors are difficult to classify, *i.e.*, it is not possible to pick out what might be called the fundamental odor sensations. One classification groups odors into (1) pure odors, (2) odors mixed with sensations from the mucous membrane of the nose, and (3) odors mixed or confused with tastes. The pure odors are further subdivided into nine classes, namely, ethereal, aromatic, fragrant, ambrosial, garlic, burning odors, goat odors, repulsive odors, and nauseating or fetid odors.

The sensation of smell develops quickly after the contact of the odoriferous stimulus, and may last a long time. When the stimulus is repeated, the sensation very soon dies out, the end-organs of the sensory cells quickly becoming exhausted. This accounts for the fact that one may easily become accustomed to foul odors and is an advantage when foul odors have to be endured. On the other hand, it emphasizes the importance of acting on the first sensation of a disagreeable odor, so as not to become accustomed to it.

The olfactory center in the brain is widely connected with other areas of the cerebrum. Our olfactory memories are good. The sense of smell is closely connected with the bodily appetites.

HEARING

The auditory apparatus consists of (1) the external ear; (2) the middle ear, or tympanic cavity; (3) the internal ear, or labyrinth; and (4) the acoustic center and acoustic nerve.

External ear. — The external ear consists of an expanded portion named the pinna or auricula, and the external acoustic meatus, or auditory canal.

The pinna projects from the side of the head. With the exception of the lower portion, it consists of a framework of cartilage, containing some adipose tissue and muscles. In the lower portion, which is called the lobe, the cartilage is replaced by connective tissue. The pinna is covered with skin, and joined to the surrounding parts by ligaments and muscles. It is very irregular in shape. It is thought that the pinna serves to collect sound waves and direct them toward the external acoustic meatus.

The external acoustic meatus (**external auditory canal**) is a tubular passage, about 2.5 cm. (1 in.) in length, which leads from the concha to the tympanic membrane. It forms an S-shaped curve and is directed inward, forward, and upward, then inward and backward. Lifting the pinna upward and backward tends to straighten the canal; but in children it is best straightened by drawing the pinna downward and backward. The external portion of this canal consists of cartilage, which is continuous with that of the pinna; the internal portion is hollowed out of the temporal bone. It is lined by a prolongation of the skin, which in the outer half of the canal is very thick and not at all sensitive, and in the inner half is thin and highly sensitive. Near the orifice the skin is furnished with a few hairs, and farther inward with modified sweat-glands, and the ceruminous glands, which secrete a yellow, pasty substance called cerumen, or earwax. These hairs and the cerumen serve to protect the ear from the entrance of foreign substances.

The *tympanic membrane* (membrana tympani) separates the auditory canal from the tympanic cavity. It consists of a thin layer of fibrous tissue covered externally with skin and internally with mucous membrane.

Middle ear. — The middle ear, or tympanic cavity, is a small, irregular bony cavity, situated in the petrous portion of the temporal bone. It is so small that probably five or six drops of water would completely fill it. It is separated from the external auditory canal by the tympanic membrane, and from the internal ear by a very thin[3] bony wall in which there are two small openings; the *fenestra vestibuli* (*ovalis*), and the *fenestra cochleæ* (*rotunda*). In the posterior or mastoid wall there is an opening into the mastoid antrum and mastoid cells and because of this, infection of the

[3] Only about $\frac{1}{24}$ inch in thickness.

middle ear may extend into the mastoid cells and cause mastoiditis.[4] In the anterior or carotid wall is an opening into the auditory tube, a small canal which leads to the naso-pharynx. Thus there are five openings in the middle ear, namely, the opening between it and the auditory canal; the fenestra vestibuli and the fenestra cochleæ which connect with the internal ear; the opening into the mastoid cells, and the opening into the auditory tube. The walls of the tympanic cavity are lined with mucous membrane which is continuous anteriorly with the mucous membrane of the auditory tube and posteriorly with that of the mastoid antrum and mastoid cells.

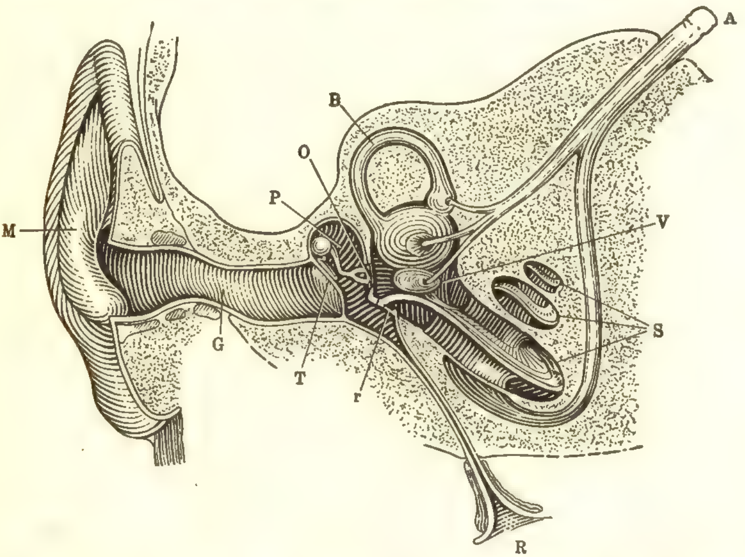


Fig. 246. — Diagram of a Section of the Right Ear. *M*, concha; *G*, external acoustic meatus; *T*, tympanic membrane; *P*, middle ear or tympanic cavity; *O*, fenestra vestibuli; *r*, fenestra cochleæ. The chain of tympanic ossicles extends from *T* to *O*. *R*, Eustachian or auditory tube; *V*, *B*, *S*, bony labyrinth; *V*, vestibule; *B*, semicircular canal; *S*, cochlea; *A*, acoustic nerve dividing into branches for vestibule, semicircular canals, and cochleæ.

Ossicles. — Stretching across the cavity of the middle ear from the tympanic membrane to the fenestra vestibuli are three tiny, movable bones, named, because of their shapes, the **malleus,** or hammer, the **incus,** or anvil, and the **stapes,** or stirrup. The handle of the hammer is attached to the tympanic membrane, and the opposite end or head is attached to the base of the anvil. The long process of the anvil is attached to the stapes, and the

[4] The temporal bone at this point is very porous, and any suppurative process is exceedingly dangerous, for the infection may travel inward and invade the brain.

footpiece of the stapes occupies the fenestra vestibuli. These little bones are held in position, attached to the tympanic membrane, to each other, and to the edge of the fenestra vestibuli, by minute ligaments and muscles. They are set in motion with every movement of the tympanic membrane. Vibrations of the membrane are communicated to the malleus, taken up by the incus, and transmitted to the stapes, which rocks in the fenestra vestibuli, and is therefore capable of transmitting to the fluid in the cavity of the labyrinth the impulses which it receives.

The auditory or Eustachian tube connects the cavity of the middle ear with the pharynx, and through the latter with the exterior. It is about 36 mm. ($1\frac{1}{2}$ in.) long and about 3 mm. ($\frac{1}{8}$ in.) in diameter at

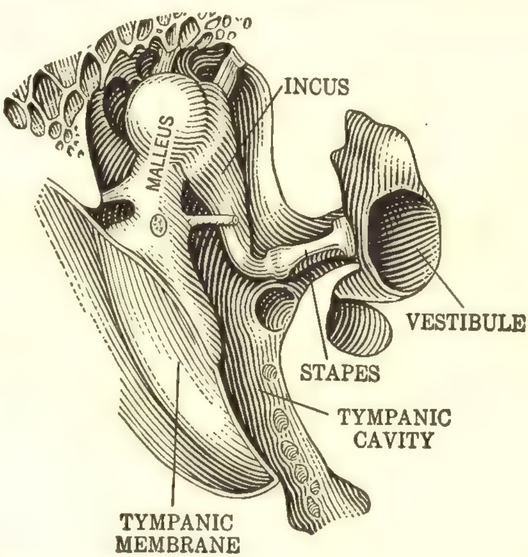


FIG. 247. — CHAIN OF OSSICLES AND THEIR LIGAMENTS, SEEN FROM THE FRONT.

its narrowest part. By means of this tube the pressure of the air on both sides of the tympanic membrane is equalized. In catarrhal conditions, the auditory tube may become occluded, and prevent this equalization. Under such conditions, hearing is much impaired until the tube is opened. The pharyngeal opening of the tube is kept closed except during swallowing, yawning, and sneezing.

Internal ear or labyrinth. — The internal ear receives the ultimate terminations of the auditory nerve, and is, therefore, the essential part of the organ of hearing. It consists of an *osseous*

labyrinth, which is composed of a series of peculiarly shaped cavities, hollowed out of the petrous portion of the temporal bone, and named from their shape:

Osseous Labyrinth
- (*a*) The vestibule.
- (*b*) The cochlea (snail-shell).
- (*c*) The semicircular canals.

Within the osseous labyrinth is a *membranous labyrinth*, having the same general form as the cavities in which it is contained though considerably smaller, being separated from the bony walls by a quantity of fluid called the *perilymph*. It does not float loosely in this liquid because in some places it is attached to the bone by bands

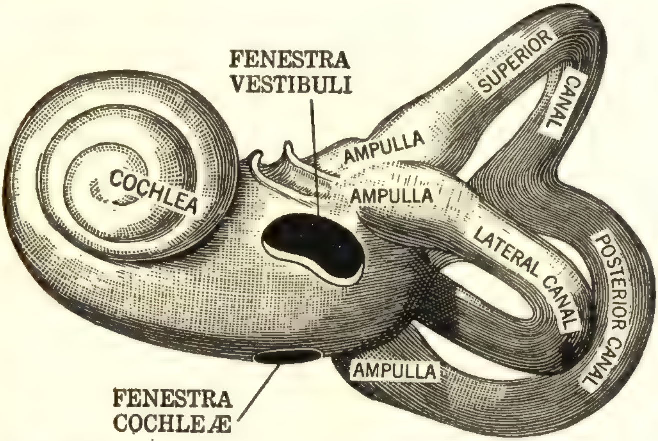


FIG. 248. — LEFT OSSEOUS LABYRINTH VIEWED FROM LATERAL SIDE. (Cunningham).

of fibrous tissue. The cavity of the membranous labyrinth contains fluid — the *endolymph* — and on its walls the ramifications of the acoustic nerve are distributed.

The vestibule is the central cavity of the osseous labyrinth, and is situated behind the cochlea and in front of the semicircular canals. It communicates with the middle ear by means of the fenestra vestibuli in its lateral or tympanic wall. The membranous labyrinth of the vestibule does not conform to the shape of the bony cavity but consists of two small sacs, called respectively the *saccule* and the *utricle*. The saccule is the smaller of the two, and is situated near the opening of the scala vestibuli of the cochlea; the utricle is larger, and occupies the upper and back part of the vestibule. These sacs are not directly connected with each other. From the posterior wall of the saccule, a canal, the *ductus endolym-*

phaticus, is given off. This duct is joined by a duct from the utricle, and ends in a blind pouch on the posterior surface of the petrous portion of the temporal bone. The utricle, saccule, and ducts contain endolymph, and are surrounded by perilymph. The inner wall of the saccule and utricle consist of two kinds of modified columnar cells, on a basement membrane. One is a specialized nerve cell provided with stiff hairs, which project into the endolymph. Between the nerve cells are supporting cells, which are not ciliated and are not connected with nerve endings. The hair cells serve as end-organs for fibers of the vestibular branch of

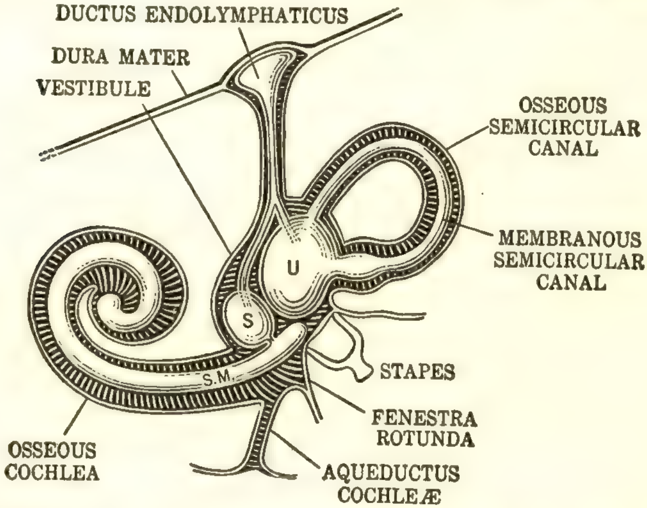


FIG. 249. — DIAGRAM OF THE MEMBRANOUS LABYRINTH OF THE INNER EAR ENCLOSED IN THE BONY LABYRINTH. *S*, saccule; *U*, utricle, and *S. M.*, scala media.

the acoustic nerve. These fibers arborize around the base of each hair cell.

The **cochlea** forms the anterior part of the bony labyrinth and is placed almost horizontally in front of the vestibule. It resembles a snail-shell and consists of a spiral canal of two and three-quarter turns around a hollow, conical, central pillar called the *modiolus*, from which a thin lamina of bone projects like a spiral shelf about halfway toward the outer wall of the canal. Within the bony cochlea is a *membranous cochlea,* which begins at the fenestra ovalis and duplicates the bony structure.

The *basilar membrane* stretches from the free border of the lamina to the outer wall of the bony cochlea, and completely divides its cavities into two passages or *scalæ*, which, however, communicate

with each other at the apex of the modiolus by a small opening. The upper passage is the scala vestibuli, which terminates at the fenestra vestibuli; and the lower is the scala tympani, which terminates at the fenestra cochlea.

From the free border of the lamina, a second membrane, called the *vestibular membrane* (Reissner[5]), extends to the outer wall of the cochlea, and is attached some distance above the basilar membrane. A triangular canal, called the *ductus cochlearis*, or *scala media*, is thus formed between the scala vestibuli above and the scala tympani below.

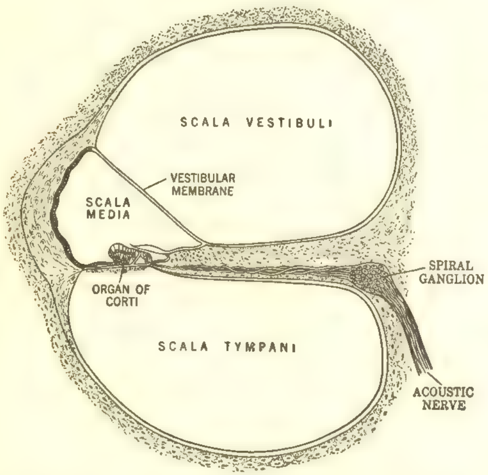


FIG. 250. — DIAGRAM OF A SECTION OF A PORTION OF THE COCHLEA. Note the tectorial membrane extending from the spiral lamina out into the endolymph over the organ of Corti.

On the basilar membrane the sound-sensitive epithelium of the *organ of Corti*[6] is located. This consists of a large number of rod-shaped cells and hair cells, extending into the endolymph of the scala media. The *tectorial membrane* projects from the spiral lamina over these cells of the organs of Corti. The fibers of the cochlear branch of the acoustic nerve arise in the nerve cells of the *spiral ganglion*, which is situated in the modiolus. These cells are bi-polar, and send one fiber toward the brain in the acoustic nerve, and the other fiber to end in terminal arborizations around the hair cells of the organ of Corti.

The **semicircular canals** are three bony canals lying above and behind the vestibule, and communicating with it by five openings, in one of which two tubes join. They are known as the *superior*, *posterior*, and *lateral* canals, and their position is such that each one is at right angles to the other two. One end of each tube is enlarged and forms what is known as the ampulla.

The semicircular ducts (membranous semicircular canals) are similar to the bony canals in number, shape, and general form, but

[5] Ernst Reissner, German anatomist, 1824–1878.
[6] Alfonso Corti, an Italian anatomist, 1822–1888.

their diameter is less. They open by five orifices into the utricle, one opening being common to the medial end of the superior and the upper end of the posterior duct. In the ampullæ the membranous canal is attached to the bony canal, and the epithelium consists of cells with hair-like processes, which project into the endolymph. Some of the terminations of the vestibular branch of the acoustic nerve are distributed to these cells. Between the hair cells are supporting cells.

The acoustic center. — Some investigators place the acoustic center in the temporal lobe of the cerebrum. Removal of both temporal lobes is followed by complete deafness. Removal of one temporal lobe is followed by impairment of hearing. Because of this it is thought that the connections of the acoustic center with the ear follow the scheme of the optic chiasm (see Fig. 258), that is, some fibers from each ear cross to the opposite side of the cerebrum and some end on the same side.

The acoustic or auditory nerve. — The acoustic nerve is a sensory nerve and contains two distinct sets of fibers, which differ in their function, origin, and destination. One set of fibers is known as the cochlear division and the other as the vestibular.

The *cochlear nerve* arises from bipolar cells in the spiral ganglion of the cochlea. The peripheral fibers pass to the cells of the organ of Corti, at which point the sound waves arouse the nerve impulses. The central fibers, forming part of the cochlear branch, pass into the lateral border of the medulla, terminating in the dorsal nucleus and ventral nucleus. From these nuclei the path is continued by secondary neurons to the auditory centers in the temporal lobe of the cerebrum.

The *vestibular nerve* arises from bipolar cells in the *vestibular ganglion* (ganglion of Scarpa), situated in the internal acoustic meatus. The peripheral fibers divide into three branches, which are distributed around the hair cells of the saccule, utricle, and the ampullæ of the semicircular canals. The central fibers, forming part of the vestibular branch, terminate in two nuclei [7] in the floor of the fourth ventricle. From these nuclei some fibers extend to the cerebellum and others pass down the spinal cord to form connections with motor centers of the spinal nerves.

In the medulla most of the fibers from each ear cross to the opposite side; therefore injury to the temporal lobe of one side affects the hearing in the ear on the opposite side, more than the

[7] Vestibular nucleus and Deiters' nucleus. Otto Friedrich Carl Deiters, German anatomist, 1834–1863.

hearing in the ear of the side affected. Destruction of the auditory centers in both lobes will result in defective hearing, but oftentimes the deafness is not complete or permanent. Because of this it is thought that the relay stations are capable of acting as subordinate auditory centers, *i.e.*, of transferring auditory impulses to the association areas.

Physiology of hearing. — All bodies which produce sound are in a state of vibration, and communicate their vibrations to the air with which they are in contact.

When these air waves, set in motion by sonorous bodies, enter the external auditory canal, they set the tympanic membrane vibrating. Stretched membranes take up vibrations from the air with great readiness. These vibrations are communicated to the chain of tiny bones stretched across the middle ear, and their oscillations are transmitted as vibrations to the perilymph of the inner ear. The movements of the perilymph, in the rhythm of the air, stimulate the nerve endings in the organ of Corti, and from these, impulses are conveyed to the center of hearing in the cerebrum. Various theories are held regarding the manner in which the organ of Corti is stimulated. In all theories, the hair cells are involved. They are thought to be stimulated by vibrations of the perilymph, tectorial membrane, basilar membrane, or combinations of these. Abnormal conditions in any part of the auditory mechanism stimulate the auditory nerve and give rise to noises that are described as rushing, roaring, humming, and ringing.

The sense of equilibrium. — Among the various means (such as sight, touch, and muscular sense) whereby we are enabled to maintain our equilibrium, coördinate our movements, and become aware of our position in space, one of the most important is the action of the vestibule and semicircular canals. Though these structures are found in the inner ear and communicate with the cochlea, it is thought that they are not connected with the sense of hearing. As a result of much experimental work, many facts regarding the effects of injury to the semicircular canals have been accumulated, but it is difficult to interpret these facts and several theories have been proposed. One theory is that movements of the head set up movements in the endolymph of the canals, and these act as stimuli to the nerve endings around the hair cells. These nerve endings serve as receptors and transmit the impulses to the cerebellum.

The canals are so arranged (Fig. 251) that any movement of the head causes an increase in the pressure of the endolymph in

one ampulla, and a corresponding diminution in the ampulla of the parallel canal on the opposite side. Thus, a nodding of the head to the right would cause a flow of the endolymph from *a* to *b* in the right superior canal, but from *b′* to *a′* in the left posterior canal. Hence the pressure upon the hairs is decreased in *a*, but increased in *a′*. Such stimulations of the sensory hairs are transmitted by fibers of the vestibular nerve, through the cell bodies of the vestibular ganglion and the axons of the acoustic nerve, to the cerebellum. The cerebellum links the impulses that arise from stimulation of the sensory nerves of the semicircular canals, joints, etc., and sends the nerve impulses on to the motor centers of the cerebrum and spinal cord.

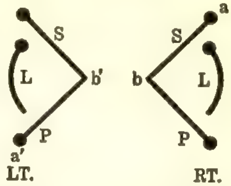


FIG. 251. — DIAGRAM SHOWING RELATIVE POSITION OF THE PLANES IN WHICH THE SEMICIRCULAR CANALS LIE. *Rt.*, right ear; *Lt.*, left ear; *S*, superior canal; *P*, posterior canal; *L*, lateral canal; *a*, ampulla of *Rt.* superior canal; *a′*, ampulla of *Lt.* posterior canal.

SIGHT

The visual apparatus consists of the bulb of the eye (eyeball), the optic nerve, and the visual center in the brain. In addition to these essential organs, there are accessory organs which are necessary for the protection and functioning of the eyeball.

Accessory organs of the eye. — Under this heading we group: (1) eyebrows, (2) eyelids, (3) conjunctiva, (4) lacrimal apparatus, (5) muscles of the eyeball, and (6) the fascia bulbi.

Eyebrows. — The eyebrows are two thickened ridges of skin, covered with short hairs. They are situated on the upper border of the orbits, and protect the eyes from too vivid light, perspiration, etc.

Eyelids. — The eyelids (palpebræ) are two movable folds placed in front of the eyes. They are covered externally by skin, and internally by a mucous membrane, the conjunctiva, which is reflected from them over the bulb of the eye. They are composed of muscle fibers and connective tissue. The latter is dense and fibrous and is known as the *tarsal plates.* The upper lid is attached to a small muscle which is called the elevator of the upper lid (*levator palpebræ superioris*). Arranged as a sphincter around both lids is the *orbicularis oculi* muscle, which closes the eyelids.

The slit between the edges of the lids is called the palpebral fissure. It is the size of this fissure which causes the appearance

of large and small eyes, as the size of the eyeball itself varies but little. The outer angle of this fissure is called the lateral palpebral commissure (*external canthus*); the inner angle, the medial palpebral commissure (*internal canthus*).

The eyelids provide protection for the eye; movable shades which (1) cover the eyes during sleep, (2) protect the eyes from bright light and foreign objects, and (3) spread the lubricating secretions of the eyes over the surface of the eyeballs.

Eyelashes and sebaceous glands. — From the margin of each eyelid, a row of short thick hairs — the eyelashes — project. The follicles of the eyelashes receive a lubricating fluid from the sebaceous glands which open into them. If this secretion becomes infected, a stye results. A stye therefore is comparable to a pimple or furuncle resulting from the infection of retained sebaceous fluid in other regions of the skin.

Lying between the conjunctiva and the tarsal cartilage of each eyelid is a row of elongated sebaceous glands — the tarsal or Meibomian glands, — the ducts of which open on the edge of the eyelid. The secretion of these glands lubricates their edges and prevents adhesion of the eyelids. A chalazion arises from the distension of the gland.

The conjunctiva. — The mucous membrane which lines the eyelids and is reflected over the forepart of the eyeball is called the conjunctiva. It is continuous with the lining membrane of the ducts of the tarsal glands, the lacrimal ducts, lacrimal sac, naso-lacrimal duct, and nose.

Lacrimal apparatus. — This apparatus consists of (1) the lacrimal gland, (2) lacrimal ducts, (3) the lacrimal sac, and (4) the naso-lacrimal duct.

The *lacrimal gland* is a compound gland, and is lodged in a depression of the frontal bone at the upper and outer angle of the orbit. It is oval in form, about the size and shape of an almond and consists of two portions, a superior and inferior, which are partially separated by a fibrous septum.

Six to twelve minute *ducts* lead from the gland to the surface of the conjunctiva of the upper lid. The secretion (tears) is usually just enough to keep the eye moist, and after passing over the surface of the eyeball is sucked through the *puncta* into two tiny *lacrimal ducts* and conveyed into the *lacrimal sac* at the inner angle of the eye. The *lacrimal sac* is the expanded upper end of the *naso-lacrimal* duct, a small canal that opens into the nose. The *caruncula lacrimalis* (caruncle) is a small reddish body situated at

the medial commissure. It contains sebaceous and sudoriferous glands, and forms the whitish secretion which collects in this region.

The lacrimal glands secrete tears. This secretion is a dilute solution of various salts in water, which also contains small quantities of mucin. The ducts leading from the lacrimal glands carry the tears to the eyeball, and the lids spread it over the surface. Ordinarily this secretion is evaporated, or carried away by the naso-lacrimal duct as fast as formed, but under certain circumstances, as when the conjunctiva is irritated, or when painful emotions arise in the mind, the secretion of the lacrimal gland exceeds the drainage power of the naso-lacrimal duct, and the fluid, accumulating

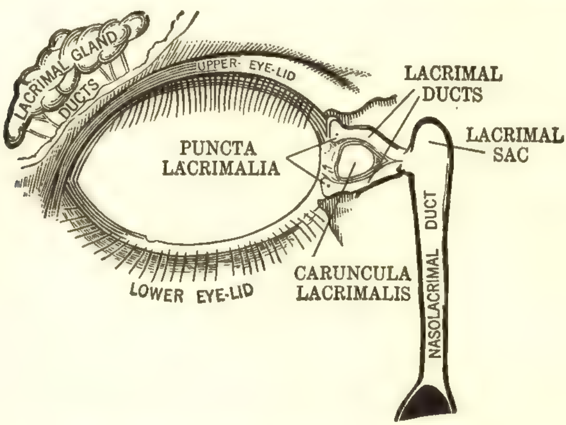


FIG. 252. — THE LACRIMAL APPARATUS.

between the lids, at length overflows and runs down the cheeks. The purpose of the lacrimal secretion is to keep the surface of the eyes moist, and to help remove foreign bodies, microörganisms, dust, etc. It is slightly antiseptic. The secretion is increased by (1) foreign bodies (molecules of volatile gases, liquids, dust, microörganisms) that come in contact with the eyeball or lids, (2) irritation of the nasal mucous membrane, (3) a bright light, and (4) emotional states. Inflammation from the nose may spread to the naso-lacrimal ducts, blocking them, and thus cause a slow dropping of tears from the inner angle of the eye.[8]

Muscles of the eye. — For purposes of description the muscles of the eye are divided into two groups: (1) intrinsic and (2) extrinsic.

[8] The lacrimal glands do not develop sufficiently to secrete tears until about the fourth month of life, hence the need for protecting a baby's eyes from bright lights, dust, etc.

The intrinsic muscles are the ciliary muscle, and the muscles of the iris. The extrinsic muscles hold the eyeball in place and control its movements. They include the four straight or recti and the two oblique, already described. The recti muscles are so arranged that the superior and inferior oppose each other, the medial and lateral do likewise. This action is comparable to the opposed action of the flexors and extensors on the arms and legs, and insures accuracy of movement. Sometimes these muscles (particularly the medial and lateral recti) are unequal in length or strength, the equilibrium of the opposed muscles is upset, and the eye is then turned in the direction of the stronger muscle, producing a squint or strabismus. There are various kinds of strabismus. Convergent strabismus is known as "cross-eye" and divergent strabismus is "wall-eye."

Nerves of the eye. — The nerves which are supplied to the eye are: (1) the optic nerve, concerned with vision only; (2) the oculomotor nerve, which supplies (*a*) the medial, superior, and inferior recti, and the inferior oblique muscles, and (*b*) the ciliary muscle, and the circular muscle of the iris (sphincter pupillæ); (3) the trochlear nerve, which controls the superior oblique muscle; (4) the abducent, which controls the lateral rectus; and (5) the ophthalmic, which is a branch of the trigeminal nerve, supplies general sensation, and sends branches to the cornea, ciliary body, and iris, and to the lacrimal gland and conjunctiva. (6) Autonomic fibers are supplied to the ciliary muscle and the radial muscle of the iris.

The orbits. — The orbits are the bony cavities in which the eyeballs are contained. Seven bones assist in the formation of each orbit, namely, frontal, malar, maxilla, palatine, ethmoid, sphenoid, and lacrimal. As three of these bones are mesial (frontal, ethmoid, and sphenoid) there are only eleven bones forming both orbits.

Each orbit is shaped like a funnel; the large end directed outward and forward forms a strong bony edge which protects the eyeball. The small end is directed backward and inward and is pierced by a large opening — the optic foramen — through which the optic nerve and the ophthalmic artery pass from the cranial cavity to the eye. A larger opening to the outer side of the optic foramen — the superior orbital fissure — provides a passage for the orbital branches of the middle meningeal artery and the nerves which carry impulses to and from the muscles, *i.e.*, the oculomotor, the trochlear, the abducent, and the ophthalmic. Each orbit contains the eyeball, muscles, nerves, vessels, lacrimal glands, fat,

the fascia bulbi, and the fascia that holds these structures in place. The inner portion is lined with fibrous tissue and contains a pad of fat which serves as a cushion for the eyeball. During many forms of illness the body fat is oxidized at an unusual rate. Under such conditions the orbital fat becomes diminished, and the eyeballs sink in the orbits.

Fascia bulbi (capsule of Tenon).[9] — Between the pad of fat and the eyeball is a serous sac — the fascia bulbi — which envelops the eyeball from the optic nerve to the ciliary region and forms a socket in which the eyeball rotates.

The bulb of the eye. — The bulb of the eye, or eyeball, is spherical in shape, but its transverse diameter is less than the antero-posterior, so that it projects anteriorly, and looks as if a section of a smaller sphere had been engrafted on the front of it.

The bulb of the eye is composed of three coats, or tunics. From the outside of the eyeball inward toward its center these are:

(1) Fibrous: (*a*) sclera; (*b*) cornea.

(2) Vascular: (*a*) choroid; (*b*) ciliary body; (*c*) iris.

(3) Nervous: retina.

It contains three refracting media. These are:

(1) Aqueous humor.

(2) Crystalline lens and capsule.

(3) Vitreous body.

Fibrous tunic. — The fibrous tunic is formed by the sclera and cornea. (*a*) The *sclera*, or *white of the eye*, covers the posterior five-sixths of the eyeball. It is composed of a firm, unyielding, fibrous membrane, thicker behind than in front, and serves to maintain the shape of the eyeball and to protect the delicate structures contained within it. It is opaque, white, and smooth externally; behind it is pierced by the optic nerve. Internally it is brown in color and is separated from the choroid by a lymph-space. It is supplied with few blood-vessels. A venous sinus — the canal of Schlemm[10] — encircles the cornea at the corneo-scleral junction. Its nerves are derived from the ciliary nerve.

(*b*) The *cornea* covers the anterior sixth of the eyeball. It is directly continuous with the sclera, which, however, overlaps it slightly above and below, as a watch crystal is overlapped by the case into which it is fitted. The cornea, like the sclera, is composed of fibrous tissue, which is firm and unyielding, but, unlike the sclera, it has no color, and is perfectly transparent; it has been

[9] Jacques René Tenon, French anatomist, 1834–1863.

[10] Friedrich S. Schlemm, German anatomist, 1795–1858.

aptly termed the "window of the eye." The cornea is well supplied with nerves (derived from the ciliary) and lymph-spaces, but is destitute of blood-vessels, so that it is dependent on the lymph contained in the lymph-spaces for nutriment.

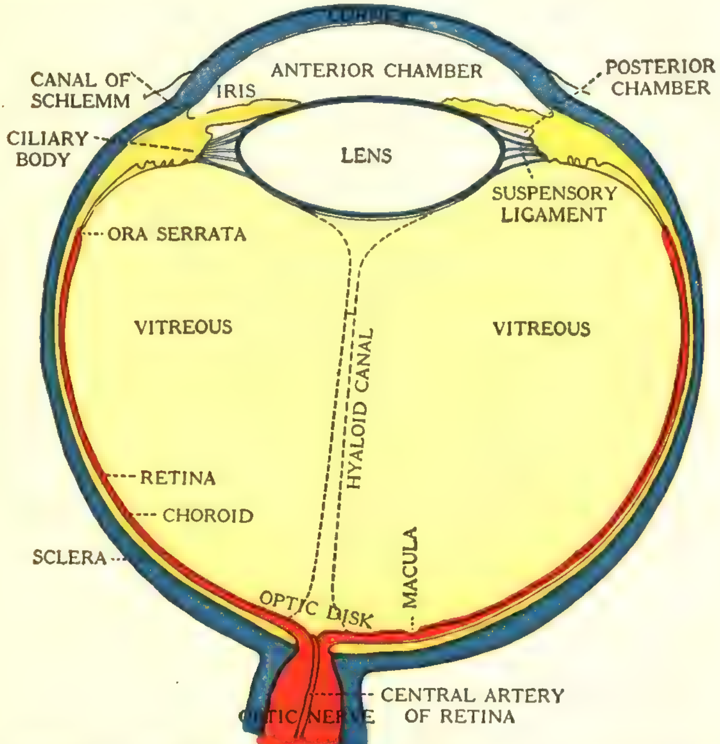


FIG. 253. — HORIZONTAL SECTION OF THE EYEBALL. (*Manual of the Diseases of the Eye*, Charles H. May.)

Vascular tunic. — The vascular tunic consists from behind forward of the choroid, the ciliary body, and the iris. (*a*) The *choroid* is a thin, dark brown membrane lining the inner surface of the sclera. It consists of a dense capillary plexus and small arteries and veins carrying blood to and from the plexus. Between these vessels are pigment cells which with other cells form a network or stroma. The blood-vessels and pigment cells render this membrane dark and opaque, so that it darkens the chamber of the eye by preventing the reflection of light. It extends to the ciliary body.

(*b*) The *ciliary body* includes the orbicularis ciliaris, the ciliary processes, and the ciliaris muscle. The orbicularis ciliaris is a

zone about 4 mm. in width, which is directly continuous with the anterior part of the choroid.

Just behind the edge of the cornea, the choroid is folded inward and arranged in radiating folds, like a plaited ruffle, around the margin of the lens. There are from sixty to eighty of these folds, and they constitute the ciliary processes. They are well supplied with nerves and blood-vessels, and also support a muscle, the ciliaris (ciliary) muscle. The fibers of this muscle arise from the sclera near the cornea, and extending backward are inserted into the outer surface of the ciliary processes and the choroid. This muscle is the chief agent in accommodation. When it contracts, it draws forward the ciliary processes, relaxes the suspensory ligament of the lens, and allows the lens to become more convex.

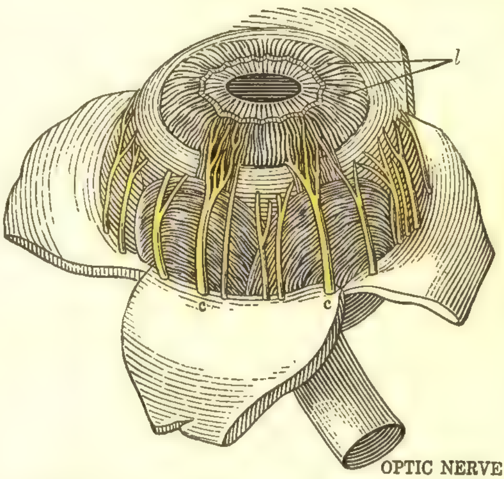


FIG. 254. — CHOROID MEMBRANE AND IRIS EXPOSED BY THE REMOVAL OF THE SCLERA AND CORNEA. *l*, iris; *c*, ciliary nerves.

(*c*) The *iris* (*iris*, rainbow) is a circular, colored disc suspended in the aqueous humor in front of the lens and behind the cornea. It is attached at its circumference to the ciliary processes, with which it is practically continuous, and is also connected to the sclera and cornea at the point where they join one another. Except for this attachment at its circumference, it hangs free in the interior of the eyeball. In the middle of the iris is a circular hole, the *pupil*, through which light is admitted into the eye chamber. The iris is composed of connective tissue containing branched cells, numerous blood-vessels, and nerves. The color of the eye is related to the number and size of pigment-bearing cells in the iris. If there is no pigment or very little the eye is blue; with increasing amounts of pigment the eye is gray, brown, or black. It also contains two sets of muscles. One set is arranged like a sphincter with its fibers encircling the pupil, and is called the *sphincter pupillæ*

(contractor of the pupil). The other set consists of fibers which radiate from the pupil to the outer circumference of the iris, and is called the *dilator pupillæ* (dilator of the pupil). The action of these muscles is antagonistic.

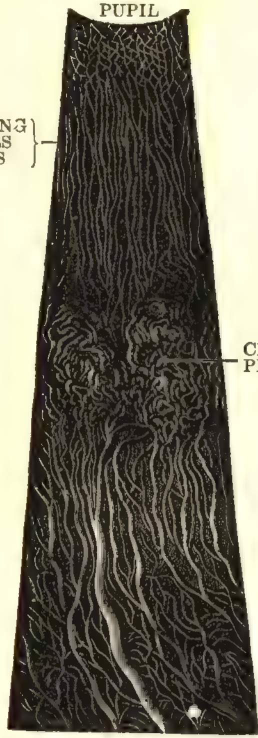


FIG. 255. — SEGMENT OF THE IRIS, CILIARY BODY, AND CHOROID. Viewed from the internal surface. (Gerrish.)

The posterior surface of the iris is covered by layers of pigmented epithelium named *uvea,* from its color being like that of a ripe grape. It is designed to prevent the entrance of light.

Function of the iris. — The function of the iris is to regulate the amount of light entering the eye, and thus assist in obtaining clear images. This regulation is accomplished by the action of the muscles described above, as their contraction or relaxation determines the size of the pupil. When the eye is accommodated for a near object, or stimulated by a bright light, the sphincter muscle contracts and diminishes the size of the pupil. When, on the other hand, the eye is accommodated for a distant object, or the light is dim, the dilator muscle contracts and increases the size of the pupil.

Nervous tunic. — The retina, the innermost coat of the eyeball, is a delicate nervous membrane which receives the images of external objects and transfers the impressions evoked by them to the center of sight in the cortex of the cerebrum. It occupies the space between the choroid coat and the hyaloid membrane of the vitreous body and extends forward almost to the posterior margin of the ciliary body where it terminates in a jagged margin known as the *ora serrata.* It consists of three sets of neurons so arranged that the cell bodies and processes form seven layers. In addition there are two limiting membranes, one membrane

(membrana limitans interna) in contact with the vitreous layer, and the second (membrana limitans externa) marking the internal limit of the rod and cone layer and a pigmented layer between the layer of rods and cones and the choroid coat.

The seventh layer is called the layer of rods and cones, and these act as end-organs or receptors for the optic nerve. It is thought

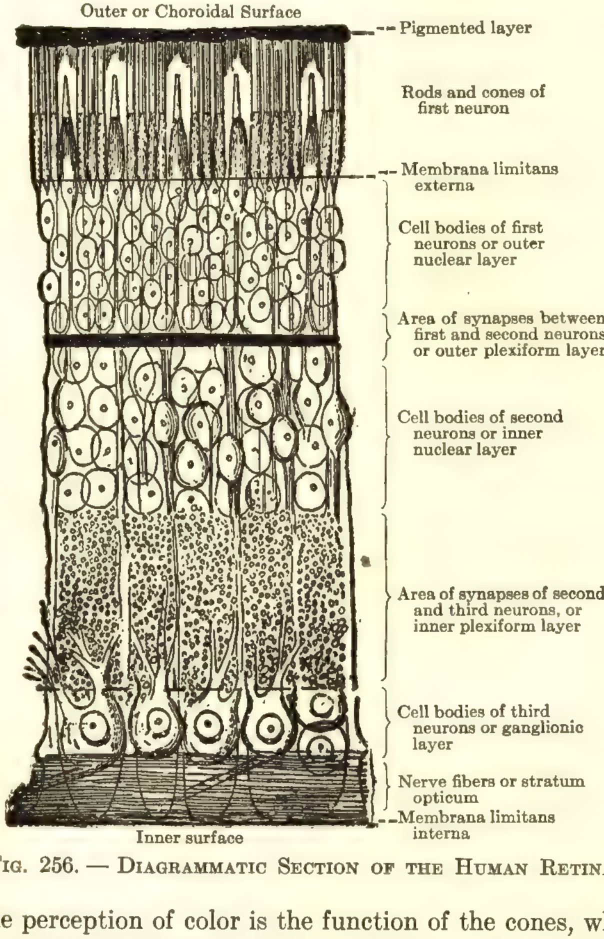


FIG. 256. — DIAGRAMMATIC SECTION OF THE HUMAN RETINA.

that the perception of color is the function of the cones, while the rods are sensitive to light and darkness and form the special apparatus for vision in dim lights. This layer is covered by pigmented epithelium. To reach this layer rays of light pass through the cornea, lens, humors, and the entire thickness of the retina. The rods contain a pigment known as *rhodopsin* or visual purple, which is bleached by light, but is constantly regenerated, it is thought, by

the pigmented epithelial cells that lie between the rods and the choroid coat.

Blind spot. — The optic nerve pierces the eyeball not exactly at its most posterior point, but a little to the inner side. This point is insensitive to light and is called the blind spot. There are no rods and cones at this spot, and rays of light falling upon it produce no sensation. The central artery of the retina [11] and its vein pass into the retina along with the optic nerve.

Macula lutea. — There is one point of the retina that is of great importance, and that is the macula lutea, or yellow spot. It is situated about 2.08 mm. ($\frac{1}{12}$ in.) to the outer side of the exit of the optic nerve, and is the exact center of the retina. In its center is a tiny pit, — *fovea centralis,* — which is the center of direct vision. At this point there is an absence of rods but a great increase in the number of cones. This is the region of greatest visual acuity.

Refracting media. — The cornea and the aqueous humor form the first refracting medium. (1) The *aqueous humor* fills the anterior chamber; the latter is the space bounded by the cornea in front and by the lens, suspensory ligament, and ciliary body behind. This space is partially divided by the iris into an anterior and posterior chamber. The aqueous humor is a clear watery solution containing minute amounts of salts, mainly sodium chloride. It is believed that it is derived partly from the blood-vessels and partly by secretion of the neighboring epithelial cells and that it drains away through the spaces of Fontana [12] into the venous canal of Schlemm and then on into the larger veins of the eyeball.

(2) The *crystalline lens* enclosed in its capsule is a transparent, refractive body, with convex anterior and posterior surfaces. It is placed directly behind the pupil, where it is retained in position by the counterbalancing pressure of the aqueous humor in front, and the vitreous body behind, and by its own suspensory ligament formed in part by the hyaloid membrane, and in part by fibers derived from the ciliary processes. The posterior surface is considerably more curved than the anterior, and the curvature of each varies with the period of life. In infancy, the lens is almost spherical; in the adult, of medium convexity; and in the aged, considerably flattened. Its refractive power is much greater than that of the aqueous or vitreous body.

(3) The *vitreous body,* a semi-fluid albuminous tissue enclosed in a thin membrane, — the hyaloid membrane, — fills the posterior

[11] Branch of the ophthalmic artery.

[12] Felice Fontana, Italian naturalist, 1730–1805.

four-fifths of the bulb of the eye. The vitreous body distends the greater part of the sclera, supports the retina, which lies upon its surface, and preserves the spheroidal shape of the eyeball. Its refractive power, though slightly greater than that of the aqueous humor, does not differ much from that of water.

Perception of light and color. — Waves started by the motion of the molecules of bodies (especially hot bodies like the sun) cause ethereal vibrations, and these vibrations are of varying lengths. Vibrations from .0004 mm. to .0008 mm. long are called light and color waves. Those shorter than this are known as chemical or actinic rays; those much longer are electrical waves. When vibrations varying between .0004 to .0008 mm. enter the eye, they cause chemical changes in the rods and cones which give rise to impulses that are carried by the optic nerve to the brain, and result in sight. Just how this is accomplished is not known, but the rods contain a kind of pigment which is called rhodopsin or visual purple, which is thought to function in these changes.

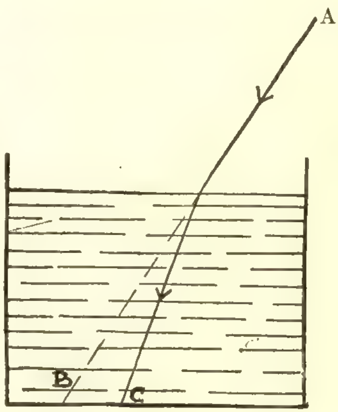


FIG. 257. — BENDING OF A BEAM OF LIGHT ENTERING WATER.

Refraction. — Light rays may be refracted or bent from their course. This is due to the fact that they travel at different rates in media of different density. For instance, light travels less rapidly in water than in air. For this reason where a ray of light in air strikes a body of water obliquely, it will be bent out of a straight line, as shown in Fig. 257. The light ray AC, instead of following the straight line AB, is bent on striking the surface of the denser medium, thereby being bent from its direct path toward C.

The bending is in proportion to the density of the medium. The cause of the refraction of oblique rays is that all the component rays do not reach the surface of the medium at the same time and those that enter first become retarded before those entering later. A ray of light which strikes a body of water perpendicularly will not be bent because all its component rays enter the water at the same time and hence all are equally retarded. The central components of a light wave enter our eyes perpendicularly, and the sides obliquely. For clear vision the oblique rays must converge and

come to a focus with the central rays on the retina. The aqueous humor, the crystalline lens, and the vitreous humor form a system of refractory devices. Rays of light are bent or undergo refraction chiefly (1) on entering the cornea from the air, (2) on entering the lens from the aqueous humor, (3) on leaving the lens and entering the vitreous fluid.

Vision. — Visible objects reflect light rays which fall upon them. These reflected rays are brought to a focus on the rods and cones of the retina, and the resulting nerve impulses are transmitted to the optic nerve and thence through various relay stations to the centers of vision in the occipital lobes of the cerebrum. From here it is believed the impulses are transmitted to the association areas, where they awaken memories that enable us to interpret their meaning. Several theories are advanced in explanation of the way in which rays of light stimulate the receptors of the optic nerve. One theory is that light rays bring about such changes in the visual purple that pictures are produced on the receptors similar to those made on the sensitive plate of a camera. This is questioned because the visual purple is absent from the cones of the fovea centralis, which is the place of most acute vision and the part on which the light rays are focused when the eyes are accommodated for near objects. Moreover, it has been found that the sensitiveness of the fovea centralis decreases in a dim light while that of the peripheral portion of the retina where the pigment is, increases. In a bright light we try to focus the object directly on the fovea, and the reflexes controlling accommodation help to bring this about. In a dim light the tendency is to diverge the eyes and thus bring the image into the peripheral part of the retina. These facts support the assumptions that (1) in a bright light the cones of the fovea which are the chief receptors used need no sensitizing agent, but are directly affected by the light waves; (2) in a dim light the pupils are dilated and the light spreads over other parts of the retina, the visual purple is acted upon by the light waves and sensitizes the receptors in the peripheral portion so that they are stimulated by rays that otherwise would not affect them.

Binocular vision. — The value of two eyes instead of one is that true binocular vision is possible. This is distinctive in that it is stereoscopic. A stereoscopic picture consists of two views taken from slightly different angles. In stereoscopic vision, two optical images are made from slightly different angles. This gives the impression of distance and depth, and is equivalent to adding a third dimension to the visual field. The processes necessary for

binocular vision are (1) convergence or turning the eyes inward; (2) change in the size of the pupil; (3) accommodation; and (4) refraction.

(1) *Convergence.* — In binocular vision it is necessary to turn the eyes inward, in order that the placement of two images of a given object lie upon what are called corresponding points of the two retinæ. Excitation of two corresponding points causes only one sensation, which is the reason why binocular vision is not ordinarily double vision. Convergence of the eyes is brought about by innervation of the medial recti muscles and is to some extent voluntary.

The optic chiasm. — The correspondence of the two retinæ and of the movements of the eyeballs is produced by a close connection of the nerve centers controlling these phenomena and by the arrangement of the nerve fibers in the optic nerves. The optic fibers from each retina pass backward through the optic foramen, and shortly after leaving the orbit the two nerves come together, and the fibers from the inner portion of each nerve cross. This is called the optic chiasm, and is really an incomplete crossing of fibers, as the outer fibers do not cross. (See Fig. 258.)

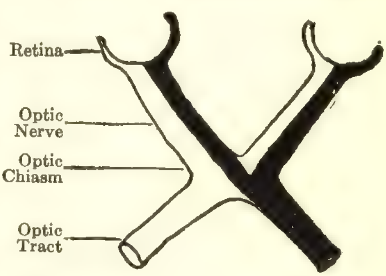


FIG. 258. — DIAGRAM OF OPTIC CHIASM.

(2) *Change in the size of pupil.* — On looking at a near object in a bright light the pupil contracts in order to direct the entering rays to the central parts of the lens, *i.e.*, the part where the convexity and the consequent refractive power are greatest; and to the fovea centralis. In a dim light the pupil is dilated, causing a diffusion of the rays on the peripheral parts of the retina where there is sensitizing purple. The contraction of the pupil is brought about by the stimulation of the circular muscle of the iris by the oculomotor nerve; in a dim light the stimulation is lessened and it dilates. In excitement, fear, etc., its dilatation is due to stimulation of autonomic nerve fibers that arrive by way of the ophthalmic branch of the trigeminal nerve.

(3) *Accommodation.* — Accommodation is the ability of the eye to adjust or focus for objects at different distances, because a sharply focused image must fall upon the retina in order to produce clear vision.

The generally accepted theory is that the ciliary muscle is the active agent in accommodation. When the eye is at rest or fixed upon distant objects, the suspensory ligament, which extends from the ciliary processes to the capsule of the lens, exerts a tension upon the lens which keeps it flattened, particularly the anterior surface to which it is attached. When the eye becomes fixed on near objects, as in reading, sewing, etc., the ciliary muscle contracts and draws forward the choroid coat, which in turn releases the tension of the suspensory ligament upon the lens, and allows the anterior surface to become more convex. The accommodation for near objects is an active condition and is always more or less fatiguing. On the contrary, the accommodation for distant objects is a passive condition, in consequence of which the eye rests for an indefinite time upon remote objects without fatigue.

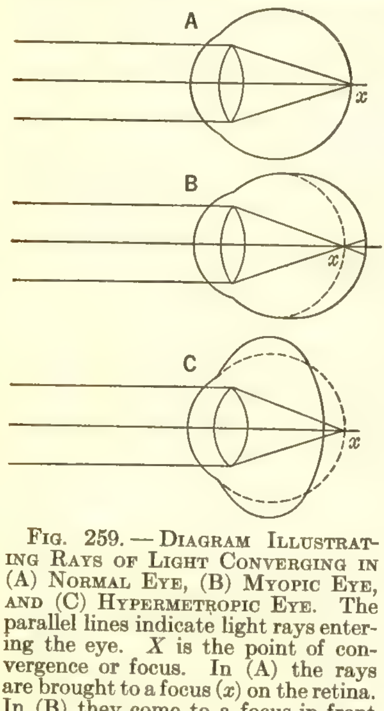


FIG. 259. — DIAGRAM ILLUSTRATING RAYS OF LIGHT CONVERGING IN (A) NORMAL EYE, (B) MYOPIC EYE, AND (C) HYPERMETROPIC EYE. The parallel lines indicate light rays entering the eye. *X* is the point of convergence or focus. In (A) the rays are brought to a focus (*x*) on the retina. In (B) they come to a focus in front of the retina. In (C) they would come to a focus behind the retina.

(4) *Refraction.* — Rays of light entering the eye are refracted or bent so that they come to a focus on the retina. It occurs because of the varying densities of the successive refractive media.

Inversion of images. — Due to refraction, light rays as they enter the eye cross each other and cause the image of external objects on the retina to be *inverted.* The question then arises, "Why is it that objects do not appear to us to be upside down?" This question is easily answered if we remember that our actual visual sensations take place in the brain, and that the projection of these sensations to the exterior is a secondary act that has been learned from experience.

Abnormal conditions that interfere with refraction. — The normal eye is one in which at a distance of about twenty feet parallel rays of light focus on the retina, when the eye is at rest. Such an eye is designated as emmetropic, or normal. Any abnormality in the refractive surfaces or the shape of the eyeball prevents this focusing of parallel rays and makes the eye ametropic, or abnormal.

The most common refractive troubles are: (1) hypermetropia, (2) myopia, (3) presbyopia, and (4) astigmatism.

Hypermetropia. — Hypermetropia or far-sightedness is a condition in which rays of light from near objects do not converge soon enough and are brought to a focus behind the retina.

A hypermetropic eye must accommodate slightly for distant objects and over-accommodate for near objects. Hypermetropia is usually caused by a flattened condition of the lens or cornea, or an eyeball that is too shallow, and convex lenses are used to concentrate and focus the rays more quickly.

Myopia. — Myopia or near-sightedness is a condition in which rays of light converge too soon, and are brought to a focus before reaching the retina. This is the opposite of hypermetropia and is caused by a cornea or lens that is too convex, or an eyeball of too great depth. This condition is remedied by wearing concave lenses, which cause parallel rays of light to diverge before they converge and focus on the retina.

Presbyopia. — Presbyopia is a defective condition of accommodation in which distant objects are seen distinctly, but near objects are indistinct. This is a physiological process which affects every eye sooner or later. It is said to be caused by a loss of the elasticity of the lens and lack of tone of the ciliary muscle.

Astigmatism. — Astigmatism means that the curvature of the refracting surfaces is unequal, *e.g.*, the cornea is more curved vertically than it is in a horizontal direction, or vice versa.

The commonest form is that in which the vertical curvature is greater than the horizontal, and is described as regular astigmatism "according to rule." Regular astigmatism is remedied by the use of cylindrical lenses, the focal length of which is different in two meridians at right angles to one another.

SUMMARY

- Sensory Unit
  - Peripheral end-organ or receptor.
  - Sensory path through which the impulses are conveyed.
  - A center in the nervous system for interpretation or linkage with motor nerves.
  - Function — Enables us to derive information about ourselves, one another, and the world in which we live.

- Sensation
  - The conscious result of processes which take place within the brain due to impulses derived from receptors.
  - Classifications
    - Old classification
      - Special — sight, hearing, touch, taste, smell.
      - General — all other sensations.
    - Based on the part of the body to which the sensation is projected
      - External or those in which the sensations are projected to the exterior of the body, *i.e.*, sight, hearing, taste, smell, pressure, and temperature.
      - Internal or those in which the sensations are projected to the interior of the body, *i.e.*, pain, muscle sense, sensations from the semicircular canals and vestibule of the internal ear, hunger, thirst, sexual sense, and fatigue.

Classification

- **Receptors**
  - Based on location of stimuli
    - Exteroceptors stimulated by forces outside the body.
    - Proprioceptors stimulated by activities that occur in muscles and articulations.
    - Interoceptors stimulated by substances or conditions within the viscera.
  - Based upon the kind of stimuli
    - Chemo-receptors stimulated by suitable concentration of substances in solution, *e.g.*, taste, smell, etc.
    - Mechanico-receptors stimulated by mechanical pressure or vibratory impacts, *e.g.*, sound, touch, etc.
    - Radio-receptors stimulated by radiant energy, *e.g.*, light, heat, cold, etc.

Cutaneous Sensations

- Surface of skin is a mosaic of sensory spots which coincide with location of special end-organs for pressure, cold, heat, or pain.
- **Classification**
  - Epicritic
    1. Fibers for heat, cold, light pressures, and tactile discriminations.
    2. Fibers for small difference of temperature, *i.e.*, between 26° C. and 37° C. (78.8° F. and 98.6° F.).
  - Protopathic
    1. Fibers for pain.
    2. Fibers for heat above 37° C. (98.6° F.).
    - Fibers for cold below 26° C. (78.8° F.).
    - Sensibility low, localization poor.

Pain

- Excessive stimulation of any of the sense organs causes unpleasant sensations.
- Actual pain caused by stimulation of pain receptors which are most abundant in the superficial parts of the body.
- Pain and other receptors stimulated simultaneously, sensation modified, *i.e.*, burning pain.
- **Function** — Serves as danger signal.
- Referred Pain
  - Pain arising in viscera and referred to skin area supplied with sensory fibers from the same spinal segment that supplies organ in question.

Muscular or Deep Sensibility

1. Sensory end-organs in the muscles, *i.e.*, muscle spindles.
2. Sensory end-organs situated in tendons, *i.e.*, tendon spindles or tendon organs of Golgi.
3. Afferent fibers carry impulses to centers in brain.
4. Efferent fibers carry impulses from brain to muscle.

Hunger

- Normal gastric hunger due to contractions of empty stomach, acting on nerves distributed to mucous membrane.
- Hunger contractions may be frequent and severe, even when food is taken regularly, as in diabetes.

- **Appetite**
  - Aroused in part through sensory nerves of taste and smell, associated with previous experiences.
  - Thought of food associated with appetite induces flow of saliva and gastric fluid.
- **Thirst**
  - Normal thirst sensations presumably due to stimulation of sensory nerves of pharynx.
  - Prolonged deprivation of water probably affects sensory nerves in many tissues, and interferes with the metabolism of the nervous system.
- **Nausea**
  - May be due to stimulation from the stomach, to substances in the blood, to impulses from organs of sight, taste, and smell.
- **Taste**
  - Sensory apparatus
    1. Taste-buds are end-organs.
    2. Nerve fibers of trigeminal, facial, and glossopharyngeal nerves.
    3. Center in brain.
  - Solution of savory substances must come in contact with taste-buds.
  - Taste-buds are distributed over
    - Surface of tongue.
    - Soft palate and fauces.
    - Tonsils and pharynx.
- **Tongue**
  - Freely movable muscular organ.
  - Attached to hyoid bone, epiglottis, and the glossopalatine arches.
  - Surface covered by papillæ containing capillaries and nerves
    - Vallate.
    - Fungiform.
    - Filiform.
    - Simple.
  - **Nerves**
    - Sensory
      - Lingual, branch of trigeminal.
      - Chorda tympani, branch of the facial.
      - Glossopharyngeal.
    - Motor — Hypoglossal.
  - **Sense of**
    1. Taste
    2. Temperature
    3. Pressure
    4. Pain

    are all well developed.
- **Classification of Taste Sensations**
  - **Four primary sensations**
    - Salty, bitter.
    - Acid, sweet.
  - **All others are**
    - Combinations of primary sensations.
    - Combinations of one or more plus odor.
- **Smell**
  - Sensory apparatus
    - Olfactory nerve endings.
    - Olfactory nerve fibers spread out in fine network over surface of superior nasal conchæ and upper third of septum.
    - Olfactory bulb and center in brain.
  - Odors
    - Minute particles usually in gaseous form
      - Must be capable of solution in mucus.
    - Classify
      - Pure odors
        - Ethereal, aromatic, fragrant, ambrosial, garlic, burning, goat, repulsive, fetid.
      - Odors mixed with sensations.
      - Odors mixed or confused with taste.

- **Smell**
  - Olfactory center in the brain is widely connected with other areas of the cerebrum.
  - Branches of trigeminal nerve found in lining of lower part of nose (pressure).
- **Hearing**
  - Auditory apparatus
    - External ear.
    - Middle ear or tympanic cavity.
    - Internal ear or labyrinth.
    - Acoustic or auditory nerve.
    - Acoustic center in brain.
  - Air waves enter meatus and cause vibrations of tympanic membrane. The vibrations are conveyed to nerve endings of organ of Corti, and thence by the auditory nerve to the brain.
- **EAR**
  - **External Ear**
    - Pinna or auricle
      - **Structure** — Cartilaginous framework, some fatty and muscular tissue, covered with skin.
      - **Function** — Collects sound waves.
    - External acoustic meatus
      - 2.5 cm. long, partly cartilage, partly bone.
      - Leads from the concha to the tympanic membrane.
      - Near orifice skin is furnished with hairs and ceruminous glands.
      - Ceruminous glands secrete a yellow, pasty substance.
  - **Middle Ear**
    - An irregular cavity in the temporal bone.
    - Five or six drops of water will fill it.
    - Bones
      - Malleus (hammer).
      - Incus (anvil).
      - Stapes (stirrup).
    - Five Openings
      - Opening between it and external auditory canal, covered by tympanic membrane.
      - Connect with internal ear.
        - Fenestra vestibuli at end of scala vestibuli
        - Fenestra cochleæ at end of scala tympani
      - Opening into mastoid antrum and mastoid cells.
      - Eustachian (auditory) tube — connects with the pharynx; ventilates cavity.
  - **Internal Ear**
    - Osseous Labyrinth
      - Vestibular branch of acoustic nerve distributed to vestibule and semicircular canals.
        - Vestibule behind the cochlea, in front of the semicircular canals
        - Semicircular canals
          - Three in number
          - Open into vestibule
      - Cochlea
        - A spiral canal $2\frac{3}{4}$ turns around modiolus.
        - Cochlear branch of the acoustic nerve

- **EAR**
  - **Internal Ear**
    - Membranous Labyrinth
      - Surrounded by perilymph.
      - Contains endolymph.
      - In the vestibule forms the
        - Saccule.
        - Utricle.
      - Lines the semicircular canals.
      - Lines the Cochlea
        - *Basilar membrane* extends from free border of lamina to outer wall of cochlea and separates the scala vestibuli and the scala tympani. Supports organ of Corti.
        - *Vestibular membrane* extends from free border of lamina to outer wall of cochlea and is attached above basilar membrane, forms *scala media.*
    - Acoustic Nerve
      - Cochlear arises from bipolar cells in spiral ganglion
        - Peripheral fibers from cells terminate in and around the cells of the organ of Corti.
        - Central fibers pass into the medulla and terminate in two nuclei.
      - Vestibular arises from bipolar cells in vestibular ganglion
        - Peripheral fibers terminate in hair cells of saccule, utricle, and ampullæ of the semicircular canals.
        - Central fibers pass into the medulla and terminate in two nuclei.

- **Physiology of Hearing**
  - Sonorous bodies produce air waves.
  - Air waves enter external auditory canal, set tympanic membrane vibrating, vibrations communicated to ossicles, transmitted through fenestra vestibuli to perilymph, stimulate nerve-endings in organ of Corti, impulses carried to center of hearing in brain.

- **Sense of Equilibrium**
  - Function of the vestibule and semicircular canals.
  - Lining membrane supplied with sensory hairs which connect with vestibular nerve.
  - Flowing of the endolymph stimulates the sensory hairs; this is transmitted to the vestibular branch of the acoustic nerve, thence to cerebellum.

- **Visual Apparatus**
  - Bulb of the eye.
  - Optic nerve.
  - Center in brain.
  - Accessory organs
    - Eyebrows.
    - Eyelids.
    - Conjunctiva.
    - Lacrimal apparatus.
    - Muscles of the eyeball.
    - Fascia bulbi.

Accessory Organs

- **Eyebrows**
  - Thickened ridges of skin furnished with short, thick hairs.
  - Protect eyes from too vivid light, perspiration, etc.
- **Eyelids**
  - Folds of connective tissue covered with skin, lined with mucous membrane, conjunctiva, which is also reflected over the eyeball.
  - Provided with lashes.
  - Upper lid raised by levator palpebræ superioris.
  - Both lids closed by sphincter-like muscle, orbicularis oculi.
  - Slit between lids called palpebral fissure.
  - Inner angle of slit called medial palpebral commissure (internal canthus).
  - Outer angle of slit called lateral palpebral commissure (external canthus).
  - **Function**
    1. Cover the eyes.
    2. Protect eyes from bright light and foreign objects.
    3. Spread lubricating secretions over surface of eyeball.
- **Eyelashes and Sebaceous Glands**
  - Margin of each lid a row of short hairs project.
  - Sebaceous glands connected with lashes.
  - Meibomian glands between conjunctiva and tarsal cartilage of each lid.
  - Secretion lubricates edges, prevents adhesion of lids.
- **Conjunctiva**
  - Mucous membrane, lines eyelids, and is reflected over eyeball. Continuous with mucous membrane of lacrimal ducts and nose.
- **Lacrimal apparatus**
  - Lacrimal gland — in the upper and outer part of the orbit. Secretes tears.
  - Lacrimal ducts begin at puncta and open into lacrimal sac.
  - Lacrimal sac expansion of upper end of naso-lacrimal duct. Between lateral ducts is the lacrimal caruncle.
  - Naso-lacrimal canal — extends from lacrimal sac to nose.
  - Tears
    - Secretion constant.
    - Dilute solution of various salts in water, also mucin.
    - Function
      - Keep surface of eyes moist.
      - Help to remove foreign bodies, microörganisms, dust, etc.
      - Carried off by nasal duct.
- **Muscles**
  - **Extrinsic**
    - Superior rectus.
    - Inferior rectus.
    - Medial or internal rectus.
    - Lateral or external rectus.
    - Superior oblique.
    - Inferior oblique.

- **Accessory Organs**
  - **Muscles**
    - **Intrinsic**
      - Ciliary muscle
        - Determines the position of the lens.
      - Muscles of iris
        - Contractor of pupil.
        - Dilator of pupil.

- **Nerves of Eye**
  1. Optic nerve concerned with vision only.
  2. Oculomotor controls
     - Medial rectus muscle.
     - Superior rectus muscle.
     - Inferior rectus muscle.
     - Inferior oblique muscle.
     - The ciliary muscle.
     - The circular muscle of the iris.
  3. Trochlear controls the superior oblique muscle.
  4. Abducent controls the lateral rectus muscle.
  5. Ophthalmic supplies general sensation, such as pressure, muscle sense, and pain.

- **Orbit**
  - A bony cavity formed by seven bones
    - Frontal, Malar, Maxilla, Palatine, Ethmoid, Sphenoid, Lacrimal.
  - Contains eyeball, muscles, nerves, vessels, lacrimal glands, fat, fascia bulbi, and fascia holding structures in place.
  - Lined by fibrous tissue.
  - Pad of fat — supports eyeball.
  - Fascia bulbi is a serous sac which envelops eyeball from optic nerve to ciliary region.
  - Shaped like funnel
    - Large end directed outward and forward.
    - Small end directed backward and inward.
  - **Optic foramen** — opening for passage of optic nerve and ophthalmic artery.
  - **Superior orbital fissure** — opening for passage of orbital branches of middle meningeal artery and oculomotor, trochlear, abducent, and ophthalmic nerves.

- **Bulb of the Eye**
  - Spherical in shape, but it projects anteriorly.
  - **Tunics**
    1. Fibrous — sclera and cornea.
    2. Vascular — choroid, ciliary body, and iris.
    3. Nervous — retina.
  - **Media**
    1. Cornea and aqueous humor.
    2. Crystalline lens and capsule.
    3. Vitreous body.

- **Protective Tunics**
  - **Sclera**
    - Tough, fibrous, opaque.
    - Covers posterior $\frac{5}{6}$ of eyeball.
    - Opaque, white and smooth externally, brown, internally.
  - **Cornea**
    - Fibrous, transparent — covers $\frac{1}{6}$ of eyeball.
    - Well supplied with nerve fibers.

Vascular Tunic

- **Choroid**
  - Composed of dense capillary network and stroma of cells, some of which are pigmented, lines the sclera.
- **Ciliary Body**
  - Includes the orbicularis ciliaris, the ciliary processes, and the ciliaris muscle. The orbicularis ciliaris is a zone about 4 mm. in width which is continuous with anterior part of the choroid.
  - Ciliary processes 60 to 80 radiating folds, arranged like a plaited ruffle around the margin of the lens.
  - Support ciliaris muscle — action of this muscle determines the position of the lens.
- **Iris**
  - A circular colored disc suspended in front of lens and behind cornea. Hangs free except for attachment at circumference to the ciliary processes and choroid. Central perforation — pupil.
  - Pupil contracted by circular or sphincter muscle.
  - Pupil dilated by radial or dilator muscle.
  - Composed of connective tissue, containing numerous blood-vessels and nerves. Contains pigment cells.
  - **Function** — Regulates size of pupil and thereby amount of light entering eye.

Nervous Tunic or Retina

Nervous layer — contains elements essential for reception of rays of light. Situated between the choroid coat and hyaloid membrane of the vitreous humor, extends forward and terminates in the *ora serrata*.

Has three sets of neurons so arranged that seven layers are formed. These are held in place by neuroglia, and two membranes. Counting from the hyaloid membrane outward: Membrana limitans interna.

1. Nerve fibers or stratum opticum.
2. Cell bodies of third neurons or ganglionic layer.
3. Area of synapses of second and third neurons or inner plexiform layer.
4. Cell bodies of second neurons or inner nuclear layer.
5. Area of synapses between first and second neurons or outer plexiform layer.
6. Cell bodies of first neurons or outer nuclear layer.
   Membrana limitans externa, marking internal limit of rods and cones.
7. Rods and cones of first neurons are end-organs or receptors for the optic nerve.
   Pigmented layer between rods and cones and choroid.

- **Blind Spot**
  - Entrance of optic nerve and central artery and vein of the retina.
  - There are no rods and cones.
  - Totally insensitive to light.
- **Macula Lutea**
  - 2 mm. outer side of blind spot.
  - Central pit — fovea centralis — is the center of direct vision.

- **Refracting Media**
  - **Aqueous Humor**
    - Aqueous chamber is between cornea in front, and lens, suspensory ligament, and ciliary body behind. Aqueous humor is a watery solution containing minute amounts of salts.
    - Secreted by epithelium, drains away through canal of Schlemm.
  - **Crystalline Lens**
    - Transparent, refractive body enclosed in an elastic capsule.
    - Double convex in shape. Situated behind the pupil.
    - Held in position by counterbalancing of the aqueous humor, vitreous body, and the suspensory ligament.
  - **Vitreous Body**
    - Semi-fluid, albuminous tissue enclosed in hyaloid membrane.
    - Fills the posterior four-fifths of the bulb of the eye, distends the sclera, and supports the retina.

- **Perception of light and color**
  - Waves started by the motion of molecules of hot bodies cause vibrations in ether.
  - Waves vary in length
    - Electrical waves — may be miles long.
    - Light waves — between .0004 to .0008 mm. in length.
    - Chemical waves — are shorter than light waves.

Refraction — Bending or deviation in the course of rays of light, in passing obliquely from one transparent medium into another of different density.

- **Vision**
  - Visible objects reflect light waves which fall upon them.
  - These reflected rays are brought to focus on receptors (rods and cones) of the retina, transmitted to the optic nerve, and thence to centers of vision in occipital lobe of cerebrum, from here to association areas.
  - Various theories are suggested to account for vision.

- **Processes necessary for binocular vision**
  1. Convergence or turning the eyes inward in order to place the image on corresponding points of the two retinæ.
  2. Change in the size of the pupil — contracts in a bright light — dilates in a dim light.
  3. Accommodation — Ability of the eye to adjust itself so that it can see objects at varying distances.
  4. Refraction — bending of light rays entering the pupil so they come to a focus on the retina.

- **Abnormal Conditions**
  - **Hypermetropia**
    - Far-sightedness.
    - Cause — Rays of light do not converge soon enough.
  - **Myopia**
    - Near-sightedness.
    - Cause — Rays of light converge too soon.
  - **Presbyopia**
    - Defective condition of accommodation in which distant objects are seen distinctly, but near objects are indistinct.
  - **Astigmatism**
    - Condition in which the curvature of the refracting surfaces is defective.

CHAPTER XXIV

REPRODUCTIVE SYSTEM

The purpose of this chapter is to present the anatomy and physiology of the organs concerned with the function of reproduction.

Puberty and adolescence. — As the individual develops, the elements of the reproductive organs are among the first to be differentiated. In fact, many authorities consider them to be differentiated in the zygote. During fetal life, infancy, and childhood, these organs develop at somewhat the same rate as other parts of the body. They attain functional maturity at the time of puberty. At this time the boy begins to develop into a man, and the girl begins to develop into a woman. In temperate climates the age at which boys usually attain puberty is about fifteen or sixteen years; in girls about a year younger, at fourteen. In southern countries it is somewhat earlier, and in arctic regions, a year or two later. However, no fixed rule can be given, as the time of arrival at puberty varies with every individual, depending on race, temperament, hygiene, and general surroundings.

Puberty is indicated in the male by the production of functional spermatozoa, in the female by the onset of ovulation and menstruation. At birth the testes contain thousands of immature spermatocytes, and the ovaries contain thousands of primitive germ cells, but these do not mature until the onset of puberty. Puberty is also marked by the gradual appearance of the secondary sex characteristics. In the male the larynx increases in size and accentuates the prominence called "Adam's Apple," the voice changes, the external genitals grow somewhat rapidly, and hair grows on the face, pubes, axillæ, and other parts of the body.

The girl undergoes a gradual change in figure, the hips broaden, the breasts develop, and hair grows on the pubes and axillæ. It is at this time that menstruation begins.

In both sexes body growth becomes specially increased at this time, and there is a rapid but varying degree of mental change. These changes are not accomplished at once, but extend over considerable time. The years during which they are taking place are

known as the period of adolescence. The adolescent period extends from puberty until 25 to 30 years in the female and until 28 to 32 years in the male.

MALE ORGANS OF GENERATION

These are: (1) two testes which produce the spermatozoa, and internal secretions, (2) two seminal ducts (ductus deferentes), (3) two seminal vesicles, (4) two ejaculatory ducts, (5) two spermatic cords, (6) the scrotum, (7) the penis and urethra, (8) the prostate gland, and (9) two bulbourethral (Cowper's) glands.

Testes. — The testes are two glandular organs which are suspended from the inguinal region by the spermatic cord, and are surrounded and supported by the scrotum. Each gland weighs 10.5 to 14 gm. and consists of two portions: (1) the testis, and (2) the epididymis.

(1) The *testis* is ovoid in shape and covered exteriorly by fibrous tissue which sends incomplete partitions into the central portion of the gland, dividing it into communicating cavities. In these cavities are winding tubules (seminiferous tubules) which are surrounded by blood-vessels and held together by interstitial tissue. These tubules inosculate in a sort of mesh (rete testis) and finally all unite in the epididymis.

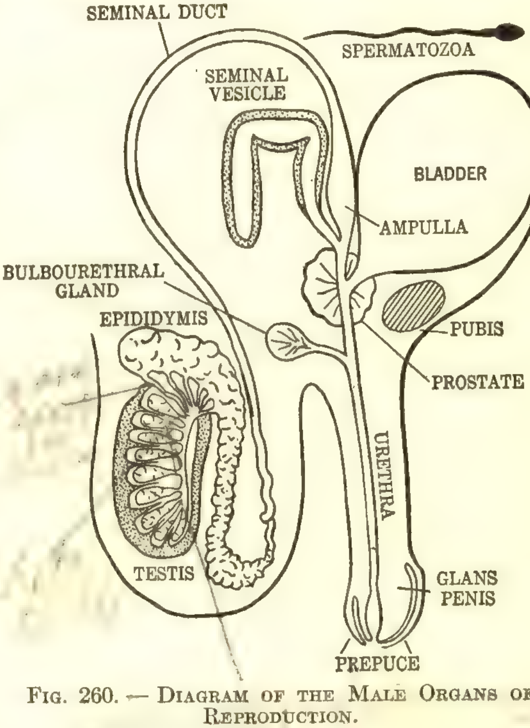


FIG. 260. — DIAGRAM OF THE MALE ORGANS OF REPRODUCTION.

(2) The *epididymis* is a long, narrow body, which lies along the upper posterior portion of the testis and consists of a tortuous

tubule, which is lined with mucous membrane, and contains some muscular tissue in its walls. If unraveled it is found to be about 5 m. (20 ft.) long. It connects the testis with the seminal duct.

Function. — The function of the testes is the production of spermatozoa, and internal secretions. If the testes are removed before puberty, the boy remains undeveloped, the enlargement of the larynx does not occur, there is no growth of hair on the face, and the features are infantile. The thymus, pituitary, and cortex of the adrenals are increased, but the growth of the thyroid is diminished, and mental development tends to be retarded.

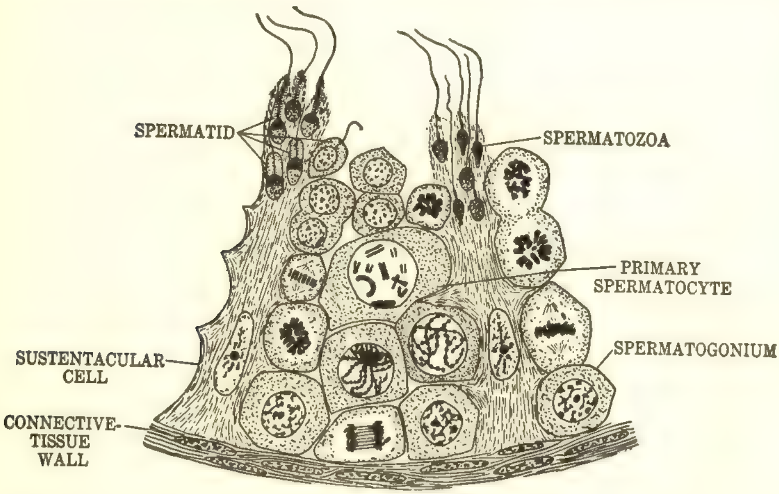


Fig. 261. — Section of the Wall of a Portion of a Seminiferous Tubule to Show Spermatogenesis or the Development of Spermatozoa. From Walter, after Arey.

Descent of the testes. — In early fetal life the testes are abdominal organs lying in front of and below the kidneys. During the process of growth they are drawn downward through the inguinal canal and shortly before birth are normally found in the scrotum. Sometimes, particularly in premature infants, a testis is found in the inguinal canal or even in the abdominal cavity; as a rule it soon descends and occupies its proper position; but occasionally it does not descend. Non-descent of the testes into the scrotum is called *cryptorchism.* Cryptorchism may be either unilateral or bilateral.

Seminal duct (ductus deferens). — Each duct is a continuation of the epididymis, and is the excretory duct of the testis. After a very devious course it reaches the prostate gland, which lies in front of the neck of the bladder. Here each duct ends by joining

the duct from the corresponding seminal vesicle to form one of the ejaculatory ducts. Each consists of three coats: an external areolar, a middle muscular, and an internal mucous coat.

The seminal vesicles. — The seminal vesicles are two membranous pouches placed between the bladder and the rectum. They are pyramidal in form, with the broad ends directed backward and

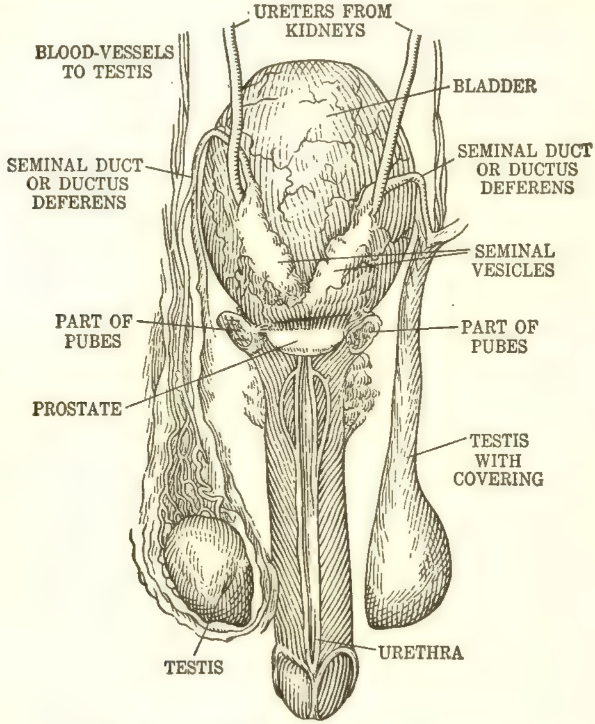


FIG. 262. — MALE GENERATIVE ORGANS.

lateralward. The anterior portions converge, become narrowed, and unite on either side with the corresponding seminal duct to form the ejaculatory duct.

Function. — The seminal vesicles are glands which add a secretion of their own to the semen. They are said by some to act as reservoirs for semen.

The ejaculatory ducts. — The ejaculatory ducts are two in number, one on each side of the middle line. They are formed by the union of the seminal vesicle with the seminal duct, descend, one on each side, and passing between the lobes of the prostate gland, finally reach the urethra into which they open and discharge their

contents. Each has an external areolar, middle muscular, and internal mucous coat.

The spermatic cords. — Each cord consists of a seminal duct, an artery, veins (forming a plexus called the pampiniform plexus), lymphatics, nerves, and connecting areolar tissue covered with fascia that is continuous with that covering the testis. These structures come together and form a cord just above the inguinal ring, through which the cord passes, and descends into the scrotum, where it connects with the posterior surface of the testis.

The scrotum. — The scrotum is a pouch consisting of (1) the integument, a layer of thin relatively dark skin, disposed in folds or rugæ and in the adult covered with short hairs; and (2) the dartos tunic consisting of plain muscle fibers. The dartos sends in a fold of tissue which serves as a partition dividing the interior of the scrotum into two chambers. The scrotum contains and supports the testes, and parts of the spermatic cords. The tissues of the scrotum are continuous with those of the groin and the perineum.

The penis. — The penis is an organ suspended from the front and sides of the pubic arch. It is composed of three cylindrical masses of cavernous tissue bound together by fibrous tissue and covered with skin. Two of the masses are lateral and are known as the corpora cavernosa penis; the third is median and is termed the corpus cavernosum urethræ because it contains the urethra. The term cavernous tissue is used because of the relatively large size of the venous spaces which exist in this tissue. It is also described as erectile tissue because the venous spaces may become distended with blood, thus enlarging the tissue and increasing its turgidity. The skin covering the penis is continuous with that covering the scrotum, the perineum, and the pubes. At the end of the penis there is a slight enlargement known as the glans penis, in which the urethral orifice is situated. In the region of the glans, the loose integument of the penis becomes folded inward, and then backward upon itself, forming the prepuce or foreskin. Sometimes this foreskin covers the glans too tightly. This condition is known as *phimosis*.

The male urethra extends from the urethral orifice in the bladder to the external orifice at the end of the penis. The length is usually given as 17.5 to 20 cm. (7–8 in.), a large part of which lies inside the pelvis. It is lined with mucous membrane and furnished with numerous muscular fibers.

The prostate. — The prostate gland is situated immediately below the internal urethral orifice. It is about the size of a chest-

nut and consists of a dense fibrous capsule containing glandular and muscular tissue. The glandular tissue consists of tubules which communicate with the urethra by minute orifices.

Function. — The function of the prostate gland is to secrete the prostatic fluid, which is an essential element of the seminal fluid.

The bulbo-urethral glands (Cowper's[1] glands). — These are two small bodies about the size of peas situated one on each side of the prostate gland. Each one is provided with a duct about 2.5 cm.

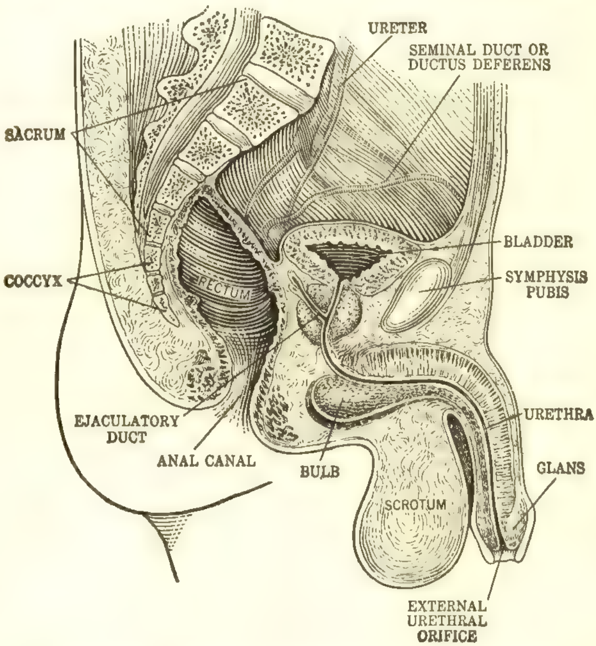


FIG. 263. — MEDIAN SECTION OF MALE PELVIS.

(1 in.) in length which terminates in a minute orifice in the wall of the urethra. These glands secrete a viscid fluid, which goes to form part of the seminal fluid.

Semen. — The semen is a fluid derived from the testes, seminal vesicles, prostate gland, and the bulbo-urethral glands. It is a grayish white, viscid fluid containing water, mucin, proteins, salts, and about 70,000,000 spermatozoa per cu. mm. On the average, three to five cu. cm. leave the urethra at a time. This amount would contain some 250,000,000 spermatozoa. Discharge of semen is initiated by peristaltic waves moving along the tubes

[1] William Cowper, English surgeon, 1666–1709.

leading from the testes. It is ejaculated through the urethra under control of the bulbocavernosus and ischiocavernosus muscles. The nerve fibers concerned belong to the pudendal plexus which arises from the sacral spinal nerves.

FEMALE ORGANS OF GENERATION

These are: (1) the two ovaries which produce the ova, and internal secretions, (2) two uterine (Fallopian) tubes, (3) the uterus, (4) the vagina, (5) the external genitals, and (6) two breasts.

Ovaries. — The ovaries are two almond-shaped, glandular bodies, situated one on each side of the uterus, attached to the back of the broad ligament behind and below the uterine tubes. Each ovary is attached to the uterus by a short ligament, — the ligament of the ovary, — and at its tubal end to the uterine tube by one of the fringe-like processes of the fimbriated extremity. Each ovary weighs from 2 to 3.5 gm.

Structure. — If the substance of an ovary be minutely examined, it is found to consist of: (1) a layer of columnar cells which constitutes the germinal epithelium, (2) a stroma or meshwork of spindle-shaped cells with a small amount of connective tissue and an abundant supply of blood-vessels, and (3) the Graafian[2] follicles (vesicular ovarian follicles). In the cortical layer of the stroma, which is just beneath the germinal epithelium, a large number of vesicles of uniform size, about 0.25 mm. in diameter, are found. These are the follicles in their earliest condition, and are especially numerous in the ovary of a child. Between puberty and the menopause large and mature follicles are found in the same layer, also corpora lutea, which are the remains of follicles that have burst and are undergoing atrophy and absorption.

The large Graafian follicles consist of (1) an outer coat of fibrous tissue derived from the stroma, (2) a middle coat also derived from the stroma, and (3) an inner coat or lining called the *membrana granulosa* composed of several layers of cells. At one part of the mature follicle the cells of the membrana granulosa are collected into a mass called the *cumulus oöphorus* (discus proligerus), which projects into the cavity of the follicle. The cavity of the follicle contains albuminous fluid and the cumulus oöphorus contains the ovum.

At birth the ovaries are said to contain about 70,000 potential ova, closely packed in the interior of the organ, but only a small

[2] Reignier de Graaf, Dutch anatomist, 1641–1673.

number of these ever develop, as the great majority shrink and disappear. At the time of puberty the ovaries enlarge, become very vascular, and some of the follicles increase in size. As the

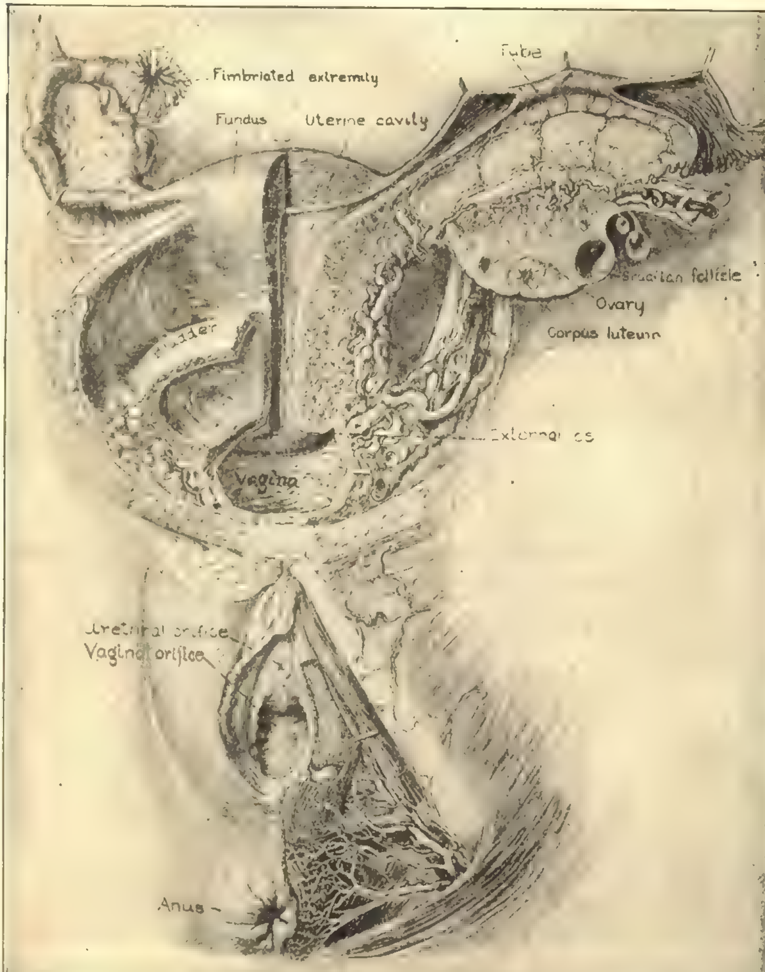


Fig. 264. — Female Generative Tract Showing both External and Internal Organs. The internal organs are represented as laid out flat, parallel with the external organs. (Reproduced from American FROHSE Life-Size Anatomical Charts. Courtesy of A. J. Nystrom & Company.)

follicles increase in size they approach the surface and begin to form small protuberances on the outside of the ovary. When fully matured, the wall of the ovary and the wall of the follicle burst, and the contents of the follicle — the fluid, the ovum, and the

surrounding cells — escape. This process of development, maturation, and rupture of a follicle is known as ovulation, and continues at regular intervals from puberty to the menopause.

The corpus luteum. — After the rupture of a follicle and the escape of the ovum the lining of the follicle is thrown into folds and vascular processes grow inward from the surrounding tissue. In this way the space is filled up and the corpus luteum is formed. The corpus luteum continues to enlarge for about two weeks after ovulation, then it disintegrates and is absorbed before the next follicle comes to maturity, but if fertilization of the ovum takes place, the corpus luteum continues to develop in size for a time and persists in its fully developed state until the end of pregnancy.

Function. — The function of the ovaries is to produce, develop, and mature the ova, and to discharge them when fully formed. It also furnishes two internal secretions which have been successfully demonstrated in experimental work with animals. There is reason to believe that additional secretions are formed, but they have not yet been successfully worked out. One secretion is formed by the Graafian (vesicular) follicles and is called theelin (œstrin). This secretion is related to the cyclic changes associated with ovulation and menstruation. The cells of the corpus luteum produce a luteal hormone. This hormone is thought to be essential for the proper implantation of the embryo in the uterine wall.

Theelin seems to act by maintaining the nutrition and mature size of the female reproductive organs. Some animals which have recurrent periods of heat or œstrus may be brought into a condition of œstrus in the absence of the ovaries, by injections of theelin.

The luteal secretion sensitizes the mucous membrane of the uterus, so that it responds to the contact of the developing ovum and assists in the process of implantation.

Comparative studies show: (1) If the ovaries are removed before puberty or remain undeveloped, the uterus remains small, there is an absence of menstruation, the breasts do not develop, and the growth of hair on the body is greater than is usual in the female. (2) If the ovaries are removed after puberty, the uterus and vagina atrophy, menstruation ceases, and various symptoms due to derangement of the nervous and metabolic processes develop. These symptoms are similar to those which occur at the time when menstruation normally ceases, *i.e.*, the menopause. The most typical are (*a*) vasomotor reactions, *i.e.*, changes in the size of the blood-vessels, which increase or diminish the amount of blood sent

to the affected part, which is usually the skin of the face and neck. These changes give rise to sensations of alternating heat and cold, sweating, dizziness, muscular pains, headache, and sometimes abnormal mental conditions; (*b*) the amount of carbohydrates that can be oxidized is diminished and obesity is common.

Uterine (Fallopian) tubes. — The uterine tubes or oviducts are two in number, one on each side, and pass from the upper angles of the uterus in a somewhat tortuous course between the folds and along the upper margin of the broad ligament, toward the sides of the pelvis. They are about 10 cm. (4 in.) long, and at the point of attachment to the uterus are very narrow, but gradually increase in size so that the distal end is larger. The margin of the distal end is surrounded by a number of fringe-like processes called *fimbriæ.* One of these fimbriæ is attached to the ovary. The uterine opening of the tube is minute, and will only admit a fine bristle; the abdominal opening is larger.

The uterine tube consists of three coats — (1) the external, or **serous,** coat is derived from the peritoneum; (2) the middle, or **muscular,** coat has two layers: an external layer of muscular fibers longitudinally arranged and an internal layer of muscular fibers circularly arranged; (3) the internal, or **mucous,** coat is arranged in longitudinal folds and covered with ciliated epithelium. It is continuous at the inner end with the mucous lining of the uterus, and at the distal end with the serous lining of the abdominal cavity. This is the only place in the body where a mucous and serous lining are continuous with one another.

Function. — The function of the uterine tubes is to convey the ova from the ovaries to the uterus. It is thought that the movement of the cilia on the fimbriæ and in the tubes produces a current which draws the ovum into the tube. After the ovum enters the tube it is carried to the uterus by the peristaltic action of the tube and the movement of the cilia. If the ovum does not become fertilized, it promptly undergoes disintegration and disappears in the secretions of the genital tract.

Occasionally an impregnated ovum remains in the tube, instead of passing into the uterine cavity. This is known as *tubal* or *tubal ectopic* pregnancy. Development may continue, but due to the erosive action of the impregnated ovum upon the tube wall hemorrhage invariably results, producing painful distention of the tube. It usually requires operation to forestall fatal bleeding. The ovum occasionally makes its way to the surface of the broad ligament or into the abdominal cavity and development of the embryo may

continue there, in rare cases to term. This is known as *abdominal* or *ectopic* pregnancy.

The uterus. — The uterus is a hollow, pear-shaped, muscular organ. It is situated in the pelvic cavity between the bladder and the rectum. Its length is estimated to be about 7.5 cm. (3 in.), its width 5 cm. (2 in.) at the upper part, and its thickness 2.5 cm. (1 in.). During pregnancy the uterus becomes enormously enlarged, attains the length of 30 cm. (a foot) or more, extends into the epigastric region, and measures about 20 to 25 cm. (8–10 in.) in width. After parturition the uterus returns to almost its original size, but is always larger than before pregnancy. After the menopause, the uterus becomes smaller and atrophies.

Divisions. — For purposes of description the uterus is divided into three parts: (1) the *fundus* is the convex part above the entrance of the tubes, (2) the *body* is the part between the fundus and the isthmus, (3) the *cervix* or neck is the lower constricted part and extends from the body of the uterus into the vagina.

The cavity of the uterus is small because of the great thickness of its walls. The part within the body is triangular in shape, and has three openings, one at each upper angle, communicating with the uterine tubes, and one, the internal orifice, opening into the cavity of the cervix below. The cavity of the cervix, which is continuous with the cavity of the body, is constricted above, where it opens into the body by means of the internal orifice (internal os), and below, where it opens into the vagina by means of the external orifice (external os). Between these two openings the canal of the cervix is somewhat enlarged.

Structure. — The walls of the uterus are thick and consist of three coats:

(1) An external **serous** coat derived from the peritoneum. It covers all of the fundus and the whole of the intestinal surface of the uterus but covers the anterior (vesical) surface only as far as the beginning of the cervix.

(2) A middle **muscular** coat, which forms the bulk of the uterine walls. It consists of layers of plain muscular tissue intermixed with blood-vessels, lymphatics, and nerves. The arrangement of the muscles is very complex, as they run circularly, longitudinally, spirally, and cross and interlace in every direction.

(3) An internal **mucous** membrane which is continuous with that lining the vagina and uterine tubes. It is highly vascular, provided with numerous uterine glands, and is covered with ciliated epithelium, except the lower third of the cervical canal, where it

loses its cilia and gradually changes to stratified squamous epithelium similar to that lining the vagina.

Blood-supply of uterus. — The uterus is abundantly supplied with blood-vessels. The blood reaches the uterus by means of the uterine arteries from the hypogastrics, and the ovarian arteries from the aorta. Where the cervix joins the body of the uterus, the arteries from both sides are united by a branch vessel called the circumflex artery. If this branch is cut during a surgical operation, or a tear of the neck during parturition extends so far as to sever it, the hemorrhage is very profuse. The arteries are remarkable for their tortuous course and frequent anastomoses. The veins are of large size, and correspond in their behavior to the arteries.

Position of the uterus. — The uterus is not firmly attached or adherent to any part of the skeleton. It is, as it were, suspended in the pelvic cavity by ligaments. A full bladder tilts it backward; a distended rectum, forward. It alters its position by gravity, or with change of posture. During gestation it rises into the abdominal cavity.

The fundus of the uterus is inclined forward, and the external orifice is directed downward and backward. *Anteversion* is the condition where the fundus turns too far forward. *Retroversion* is the condition where the fundus inclines backward. A bend may exist where the cervix joins the body. If the body is bent forward, it is described as *anteflexion;* if bent backward, *retroflexion.*

Ligaments. — The uterus is suspended by eight ligaments. Six are arranged in pairs.

1. The **broad,** or **lateral ligaments,** two in number, are folds of peritoneum slung over the front and back of the uterus, extending laterally to the walls of the pelvis. They are composed of two opposed, serous layers, and between these layers are found the following structures: (*a*) uterine tubes; (*b*) the ovaries and their ligaments; (*c*) the round ligaments; (*d*) blood-vessels and lymphatics; (*e*) nerves; and (*f*) some smooth muscle tissue.

The posterior fold covers the back of the uterus, and extends far enough below to also cover the upper one-fifth of the back wall of the vagina, when it turns up and is reflected over the anterior wall of the rectum. Thus the uterus, with and between its two broad ligaments, forms a transverse partition in the pelvic cavity, the bladder, vagina, and urethra being in the front compartment, and the rectum in the back compartment.

The smooth muscles of the broad ligaments are derived from the superficial muscular layer of the uterus. They pass out between the serous folds and become attached to the pelvic fascia.

2. Between the bladder and uterus the peritoneum forms a fold which is described as the **anterior ligament** of the uterus.

3. Behind the uterus the peritoneum forms a second and deeper fold which is described as the **posterior ligament.**

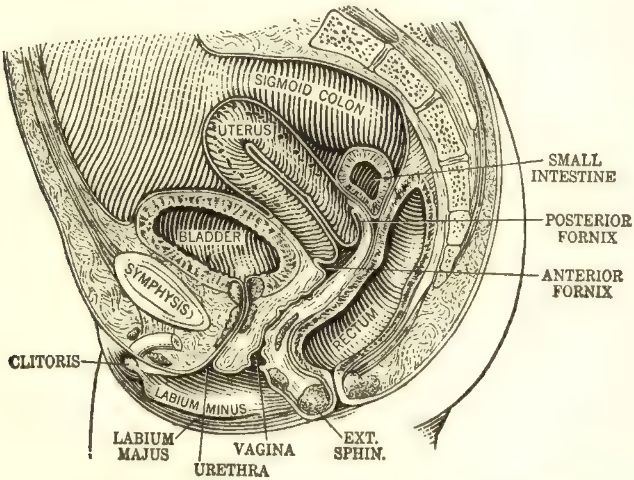


Fig. 265. — Median Section of Female Pelvis.

4. The **round ligaments** are two rounded, fibromuscular cords, situated between the folds of the broad ligament. They are about 10 to 12 cm. (4–5 in.) long, and take their origin from the upper angle of the uterus (on either side), in front of and below the attachment of the uterine tube. They extend forward, upward, and lateralward over the external iliac vessels. Each one passes through the external abdominal ring and along the inguinal canal to the labium majus in which it terminates. The round ligaments are composed of muscles, areolar tissue, blood-vessels, and nerves.

5. The **utero-sacral ligaments** pass backward from the cervix, on either side of the rectum, to the posterior wall of the pelvis. They are partly serous, partly smooth muscular tissue.

Function. — The function of the uterus is to receive the ovum from the uterine tubes, and if it becomes fertilized, to retain it during its development. Later when the ovum has developed into a mature fetus, it is expelled from the uterus, chiefly by the contractions of the uterine walls.

The vagina. — The vagina is a musculo-membranous canal situated in front of the rectum and behind the bladder. It extends downward and forward from the uterus to the vulva.

The posterior wall is about 9 cm. ($3\frac{3}{4}$ in.) long, while the anterior wall is only 6 to 7.5 cm. ($2\frac{1}{2}$–3 in.). The upper portion of the vagina surrounds the vaginal portion of the cervix, forming a deep recess behind the cervix, which is called the posterior fornix. The recesses at the front and sides are smaller and are called the anterior and lateral fornices.

Structure. — The vagina consists of an internal mucous lining continuous above with that of the uterus, and a muscular coat,

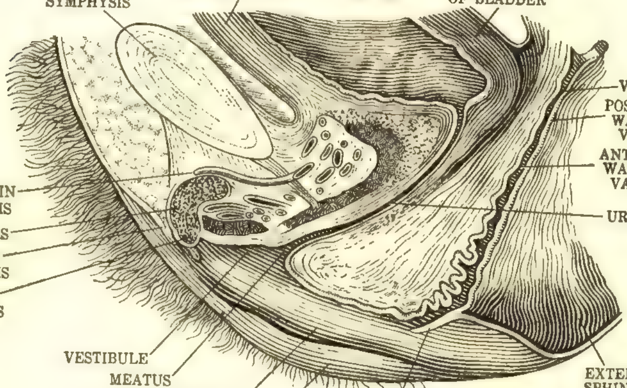


FIG. 266. — SAGITTAL SECTION OF THE VAGINA AND NEIGHBORING PARTS. (Gerrish.)

with a layer of submucous tissue between. The inner surface of the mucous membrane is thrown into two wide longitudinal folds and from these transverse folds or rugæ extend. The muscular coat increases during pregnancy, and the rugæ of the mucous coat allow of dilatation of the canal during labor and birth.

The external genitals. — The external genitals are grouped under the name of vulva or pudendum and include the following: (1) the mons pubis, (2) the labia majora, (3) the labia minora, (4) the clitoris, (5) the vestibule of the vagina, and (6) the greater vestibular glands.

The mons pubis is an eminence situated in front of the pubic symphysis. It consists of areolar, adipose, and fibrous tissue covered with skin and after puberty with hair.

The labia majora are two longitudinal folds of skin which are continuous with the mons pubis in front, and extend to within 25 mm. (an inch) of the anus behind. Between the folds of the labia there are blood-vessels, nerves, glands of the sebaceous type, adipose, and connective tissue.

The labia minora are two longitudinal folds of modified epithelium resembling mucous membrane. They are situated between the labia majora. They are joined anteriorly in the hood or prepuce of the clitoris, and extend downward and backward for about 4 cm. ($1\frac{1}{2}$ in.).

The clitoris is a small body situated at the apex of the triangle formed by the junction of the labia minora. It consists of erectile tissue, contains many vessels and nerves, and is almost completely covered by the hood or prepuce.

The vestibule of the vagina is the cleft behind the clitoris and between the labia minora. The urethral and vaginal orifices and the openings of the ducts of the greater vestibular glands are in the vestibule.

The hymen is a fold of mucous membrane which surrounds the lower part of the vagina and renders the orifice smaller. It is quite elastic and may remain intact even after childbirth, although usually ruptured. Occasionally it extends entirely across and closes the orifice altogether. This condition is spoken of as imperforate hymen.

The greater vestibular glands are two round, or oval, glands, situated on either side of the vagina. Their ducts open into the vestibule, one on either side, in the groove between the hymen and the labia minora. Their secretion lubricates the vulval canal.

Perineum. — The external surface of the floor of the pelvis, from the pubic arch to the anus, with the underlying muscles and fascia, is called the perineum. In the female it is perforated by the vagina. A wedge-shaped upward extension of the perineum, forming a septum between the vagina and the rectum, is called the perineal body. The perineum is distensible and stretches to a remarkable extent during labor. Nevertheless it is frequently torn, and when the tear is of any extent, and is not repaired, the vagina and uterus lose the support afforded by it, and various abnormal conditions follow.

PHYSIOLOGY OF THE FEMALE GENERATIVE ORGANS

Functions. — The functions of the female generative organs are: (1) the formation and development of the ova, (2) the retention and sustenance of the fecundated ovum until it develops into a mature fetus ready to live outside the body, and (3) the expulsion of the fetus.

Puberty. — Puberty is the period at which the sexual organs become matured and functional and the girl develops into a woman.

Ovulation. — Ovulation includes the process of the development and maturation of the follicle and its ovum, and the rupture

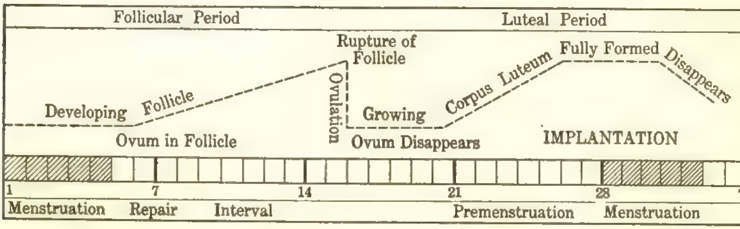


FIG. 267. — DIAGRAM TO SHOW SEQUENCE OF EVENTS IN OVARY AND IN UTERUS IN HUMAN MENSTRUAL CYCLE. After G. W. Corner.

of the follicle. Sometimes the term ovulation is used to refer simply to the shedding of ova by the ovary.

The commonly accepted theory is that about or shortly before the age of puberty the Graafian follicles begin to discharge their ova, and this process continues until the menopause.

Menstruation. — Menstruation consists of the periodical discharge of bloody fluid from the uterine cavity. When once established, it occurs on the average every twenty-eight days from the time of puberty to the menopause, with the exception of periods of pregnancy and lactation. The average duration is from four to five days. The amount of blood lost is subject to individual variations, but is usually between 100 to 200 cc. (3–7 oz.). The menstrual fluid consists of mucin, epithelial cells, and blood. The amount of destruction of the mucous membrane varies a good deal but the surface epithelium is always destroyed.

The mucous membrane of the uterus exhibits a constantly recurring cycle, which falls into four periods:

(1) *Premenstrual period,* usually five or six days *preceding menstruation.* During this period the mucous membrane becomes thicker and congested with blood.

(2) *Period of degeneration or menstruation,* usually about four or five days, during which there is capillary hemorrhage, and the epithelium of the mucous membrane is cast off.

(3) *Postmenstrual period,* usually about two or three days, during which the mucous membrane returns to its usual thickness and a new epithelium is formed.

(4) *Interval,* usually about fourteen days.

Reference to Fig. 267 will show that these periods can be considered, in relation to the ovary, as a follicular period of about fourteen days and a luteal period of about fourteen days.

Causes of menstruation. — At the present time the generally accepted view is that menstruation is dependent upon the ovaries, and that their influence is exerted through the medium of the blood. It is thought the luteal hormone is carried to the uterus by the blood, and is responsible for the hypertrophy and congestion that precedes menstruation. The fact that operations for the removal of the ovaries are followed by atrophy of the uterus and cessation of menstruation supports the theory that the ovaries are responsible for menstruation.

The menopause or climacteric. — By menopause or climacteric is meant the physiological cessation of the menstrual flow, the end of the period during which the Graafian follicles develop in the ovaries, and consequently the end of the child-bearing period. It is marked by various symptoms and atrophy of the breasts, uterus, tubes, and ovaries. The most typical symptoms are (*a*) vasomotor reactions, *i.e.*, changes in the size of the blood-vessels, which increase or diminish the amount of blood sent to the affected part, which is usually the skin of the face and neck. These changes give rise to sensations of alternating heat and cold, sweating, dizziness, muscular pains, headache, and sometimes abnormal mental conditions; (*b*) the amount of carbohydrates that can be oxidized is diminished and obesity is common. The age of menopause varies as does the age of puberty; in general, we may say the earlier the puberty the later the menopause, and *vice versa.* In temperate climates the average period for the arrival of the menopause is about the age of forty-five years.

Mammary glands. — The two mammary glands, or breasts, secrete the milk which is needed for the nourishment of the young infant. Each breast covers a nearly circular space in front of the pectoral muscles, extending from the second rib above to the sixth rib below, and from the side of the sternum to the border of the arm-pit.

Structure. — The breasts are convex in shape and are covered externally by skin. About the center of the convexity a papilla projects, which is called the nipple. The nipple contains the openings of the milk ducts, and is surrounded by a small circular area of pink or dark-colored skin, which is called the *areola*. The breasts are compound glands, and are divided by connective tissue partitions into about twenty lobes, each of which possesses its own excretory duct, which as it approaches the top of the breast dilates and forms a small reservoir in which milk can be stored during the period when the gland is active. Each duct opens by a separate orifice upon the surface of the nipple. The lobes are subdivided, and the small lobes, or lobules, are made up of the terminal tubules of the duct, which lie in a mesh of fibrous areolar tissue containing considerable fat.

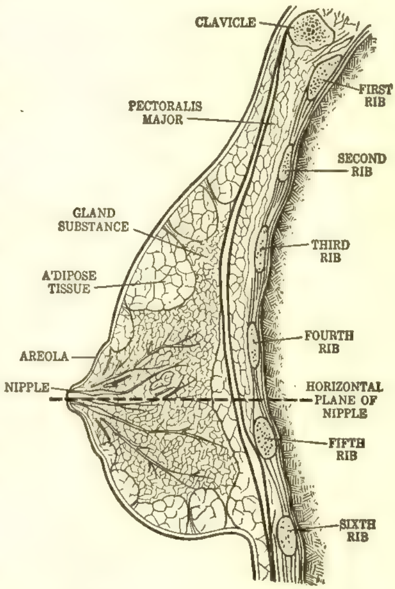


FIG. 268. — RIGHT BREAST IN SAGITTAL SECTION, INNER SURFACE OF OUTER SEGMENT. (Gerrish.)

Blood-vessels and nerves. — The mammary glands are well supplied with blood brought to them by the thoracic branches of the axillary, internal mammary, and intercostal arteries. The nerve fibers are derived from the ventral and lateral cutaneous branches of the fourth, fifth, and sixth thoracic nerves.

Development of the mammary glands. — The increase in the size of the mammary glands at the time of puberty is due to an increased development of the connective tissue and fat. The glandular tissue remains undeveloped and does not function unless conception takes place. When conception occurs, the glandular tissue undergoes a process of gradual development that produces marked changes. The breasts become larger and harder, the veins on the surface become more noticeable, the areola becomes enlarged and darkened, the nipple becomes more prominent, and toward the end of pregnancy a fluid called colostrum can be squeezed from the orifice of the ducts. After delivery the amount

of colostrum increases for a day or two, and then the secretion changes to milk.

The primary development and later functioning of the mammary glands suggest an intimate connection between these glands and the uterus, ovaries, and pituitary body. The present theory is that the increase in the size of the breasts at the time of puberty is influenced by œstrin, the follicular hormone. If the ovaries are removed before puberty, the breasts do not develop, or if the ovaries are removed after puberty, the breasts are apt to atrophy.

It was formerly thought that the development of the glandular tissue following conception was due to hormones formed by the corpus luteum, but recent experiments on animals seem to indicate that the corpus luteum alone cannot cause growth and function of the mammary glands, while these effects are readily produced by extracts of the pituitary body.[3] To what extent the ovary also is necessary to growth of the glands and lactation is as yet uncertain. Secretion after childbirth is dependent on the emptying of the glands by suckling or mechanical means.

The secretion of milk. — The secretory portion of the mammary glands is the milk ducts, and these are lined with secreting cells. Some of the constituents of the milk, *i.e.*, water, salts, and sugar, are secreted by these cells from the blood, but it is thought that the cells themselves disintegrate and form the proteins and fat. The sugar contained in the milk is lactose and the sugar of the blood is glucose, and if the first is derived from the second, it must be by a process of dehydration.

Colostrum and milk. — The secretion of the mammary glands during the first few days of lactation is called colostrum. It is a thin, yellowish fluid, composed of proteins, fat, sugar, salts, and water, but not in the same proportion as in milk. It also contains numerous cells containing large masses of fat. These are called colostrum corpuscles, and are secreting cells that are not completely broken down.

Human milk is specially adapted to the requirements of the human infant and so differs in some respects from that of all other animals. Cow's milk is most frequently substituted for human milk. The relative composition of the two can be seen in the table on the facing page.

In substituting cow's milk for human milk the differences that must be taken into consideration are not only the different relative proportions, but also the following: (1) the difference in the proteins; the protein of human milk is one-third caseinogen, and two-thirds lactalbumin, and that of cow's milk is five-sixths caseinogen and one-sixth lactalbumin; (2) the difference in

[3] See "*The Hormonal Control of Lactation,*" George W. Corner, *The American Journal of Physiology*, Vol. 95, No. 1, October, 1930.

the curds formed in the stomach; human milk curdles in small flocculi, and cow's milk curdles in large heavy curds; and (3) the reaction of human milk is practically neutral, pH 7.0 to 7.2; cow's milk is slightly acid, pH 6.6 to 6.8 when first drawn, but the acidity increases on standing; (4) human milk is sterile, and cow's milk, due to the handling it undergoes, contains a large number of microörganisms. Pasteurization destroys the microörganisms usually found in milk, but unless it is done very carefully, it also destroys the vitamins. (5) Human milk contains antitoxins and antibacterial substances that have been formed in the mother's blood, and as it is ingested directly from the breast, its germicidal power is at its height. Cow's milk may have germicidal value, but this soon deteriorates and usually is lost by the time it is given to the child.

	Human (average)	Cow's (average)
Water	88.4%	88.1%
Proteins	1.5%	3.2%
Fat	3.3%	3.9%
Lactose	6.5%	4.9%
Salts	0.3%	0.9%

Intrauterine growth. — During the period of intrauterine life growth takes place rapidly. From the union of the ovum, which is 0.2 mm. ($\frac{1}{125}$ in.) in diameter, and the spermatozoön, which is much smaller, there is developed in two weeks' time an embryo which is about 6.25 mm. ($\frac{1}{4}$ in.). At the end of four weeks it is about 12.5 mm. ($\frac{1}{2}$ in.) long, and at two months it is called a fetus, because it begins to have the appearance of a human being. The usual duration of pregnancy is ten lunar or nine calendar months. At the end of six months the fetus is sufficiently developed to live outside the mother's body, but it is frail and requires a great deal of care.

This table shows growth in weight and in height during intrauterine life.

Age of Embryo	Weight	Crown-Heel Length
8 weeks	3 grams (about $\frac{1}{10}$ oz.)	2.5 cm. (about 1 in.)
12 weeks	36 grams (about 1 oz.)	9 cm. (about 3.6 in.)
20 weeks	330 grams (about 11 oz.)	25 cm. (about 10 in.)
28 weeks	1000 grams (about 2 lbs.)	35 cm. (about 14 in.)
36 weeks	2400 grams (about 5 lbs.)	45 cm. (about 18 in.)
40 weeks	3200 grams (about $7\frac{1}{4}$ lbs.)	50 cm. (about 20 in.)

With growth of the fetus the uterus comes to occupy more and more abdominal space.

This table shows the position of the top of the uterus at different ages of the fetus.

By the end of the	*The top of the uterus has reached a level*
4th month	half way between the symphysis and umbilicus
6th month	even with the umbilicus
9th month	about even with the end of the sternum
10th month	about that of the 8th month — a little below the sternum

Parturition. — Parturition takes place, normally, at about 280 days from the beginning of the last menstrual period, and results in the birth of the child. It is brought about by the periodic contractions of the muscles of the wall of the uterus, aided by contractions of the muscles of the wall of the abdomen.

Various investigations into the causes of the onset of parturition at the end of the tenth lunar month and into the process of *labor*, have been carried on. At present, however, no single factor or sequence of groups of factors is certainly known to initiate and control the processes.

The duration of labor is variable, but the average length of time is about 12 to 18 hours. During the first stage, or *stage of dilation*, the cervix of the uterus is dilated and as a rule the amnion is ruptured and the amniotic fluid expelled; during the second stage, or *stage of descent*, the child descends through the vagina and is expelled; during the third stage, or *placental stage*, the fetal membranes are expelled.

Involution. — Following parturition, a process of involution of the uterus takes place. This involution, or rapid decrease in size of the uterus, is brought about by a gradual autolysis or "self-digestion" of the uterine wall. The process takes from six to eight weeks, and during this time the uterus resumes its original position in the pelvic cavity and approximately its original size.

SUMMARY

Life processes	Phenomena of activity and growth. Early life — anabolic processes in ascendancy, individual gains in weight and stature. Middle life — anabolic and catabolic changes balance each other, and individual holds his own. Old age — catabolic changes in ascendancy, final result is death.
Reproduction	Means by which new life is brought into existence. Sexual type depends upon the union of two cells, one of which is produced by the male and one by the female organism.

Puberty
- Age at which sex organs become matured and functional.
- Boy begins to develop into man — temperate climate about 15 years of age — essential feature is production of mature spermatozoa.
- Period marked by gradual appearance of secondary sex characteristics.
- Girl begins to develop into woman — temperate climate about 14 years of age. Essential feature is production of mature ova.
- Period marked by gradual appearance of secondary sex characteristics. Function of menstruation starts.

Adolescence — Period from puberty to late twenties or early thirties.

Male organs of generation
- 2 Testes which produce spermatozoa, and an internal secretion.
- 2 Seminal ducts (ductus deferentes or vasa deferentia).
- 2 Seminal vesicles.
- 2 Ejaculatory ducts.
- 2 Spermatic cords.
- Scrotum.
- Penis and urethra.
- Prostate gland.
- 2 Bulbo-urethral glands (Cowper's).

Testes
- Two glandular organs which produce the spermatozoa.
- **Structure**
  - **Testis** — ovoid body covered by fibrous tissue. Central portion consists of irregular cavities filled with seminiferous tubules and blood-vessels.
  - **Epididymis** — tortuous tubule, forms long, narrow body which lies along upper posterior portion of testis.
- **Location**
  - In early fetal life in abdomen below kidneys.
  - Before birth are normally drawn downward to scrotum, and are suspended by spermatic cord.
- **Function**
  - Production of spermatozoa.
  - Production of internal secretion.

Seminal Ducts
- Each duct is a continuation of the epididymis, and is the excretory duct of the testis. Serves to connect the epididymis and the seminal vesicle of each side.

Seminal Vesicles
- Two membranous pouches located between bladder and rectum. Connect seminal ducts with ejaculatory ducts.
- **Function** — Add a secretion to semen.

Ejaculatory Ducts
- Formed by union of seminal vesicle and seminal duct of each side.
- They descend, converge, pass between lobes of prostate gland, and open into the urethra.

Spermatic Cords
- Each cord consists of a seminal duct, an artery, veins forming a plexus called the pampiniform plexus, lymphatics, nerves, and connecting areolar tissue covered with fascia.
- Extend from the inguinal ring to the back of the testes.

Scrotum
- Pouch which contains testes and part of each spermatic cord.
- **Structure**
  1. Thin, dark skin, disposed in folds or rugæ, covered with short hairs.
  2. Dartos — consists of plain muscle fibers and numerous blood-vessels.

Penis
- Organ suspended from the front and sides of the pubic arch.
- Consists of three cylindrical bodies of cavernous tissue
  - Two corpora cavernosa penis.
  - A corpus cavernosum urethræ.
- Bound together by fibrous tissue.
- Covered with skin that is continuous with that covering scrotum, perineum, and the pubes.
- Urethra — extends from urethral orifice in bladder through corpus cavernosum urethræ — 17.5–20 cms. long.
- Expansion at lower extremity — glans penis — urethral orifice — covered by foreskin or prepuce.

The Prostate
- Situated immediately below the internal urethral orifice.
- Size of chestnut.
- **Consists of**
  - Fibrous capsule containing glandular and muscular tissue. Glandular tissue consists of tubules which empty into urethra.
- **Function** — Secretion of prostatic fluid.

Bulbo-urethral Glands
- Located one on each side of prostate gland — about the size of a pea — one-inch duct terminates in wall of urethra.
- **Function** — Secretion of a fluid which forms part of seminal fluid.

Semen
- Fluid derived from the various sex glands in the male.
- 70,000,000 spermatozoa per cu. mm. Nerve fibers from pudendal plexus control discharge.

Female organs of generation
- 2 Ovaries, which produce the ova and 2 internal secretions.
- 2 Uterine tubes.
- Uterus.
- Vagina.
- The external genitals.
- 2 Breasts.

Ovaries
- 2 Almond-shaped glandular bodies.
- **Attached**
  - To back of broad ligament.
  - To uterus — by ligament of ovary.
  - To tubes — by fimbriæ.
- **Size about**
  - $1\frac{1}{2}$ inches long.
  - $\frac{3}{4}$ inch wide.
  - $\frac{1}{3}$ inch thick.
- **Weight** — 2–3.5 gm.
- **Structure**
  1. Layer of germinal epithelium.
  2. Stroma or meshwork of cells.
  3. Graafian follicles
     - In early life — vesicles about 0.25 mm. in diameter.
     - Between puberty and menopause — mature follicles and corpora lutea.
     - 1. Outer coat fibrous tissue derived from stroma.
     - 2. Middle coat — theca interna derived from stroma.
     - 3. An inner coat called *membrana granulosa*.

- **Ovaries**
  - **Function**
    - Produce, develop, mature, and discharge ova.
    - Form internal secretions.
    - One secreted by Graafian follicles — called Theelin (œstrin), related to menstrual cycle.
    - One secreted by corpus luteum — called luteal secretion. Essential to implantation.
- **Uterine or Fallopian Tubes**
  - **Location**
    - Enclosed in layers of broad ligament.
    - Extend from upper angles of uterus to sides of pelvis.
  - **Divisions**
    1. Isthmus — or inner constricted portion near uterus.
    2. Ampulla — dilated portion which curves over ovary.
    3. Infundibulum — trumpet-shaped extremity — fimbriæ.
  - **Three Coats**
    1. External, or serous.
    2. Middle, or muscular.
    3. Internal, or mucous, arranged in longitudinal folds and covered with cilia.
  - **Function** — Convey ova to uterus.
- **Uterus**
  - Hollow, pear-shaped, muscular organ, placed in pelvis between bladder and rectum.
  - **Divisions**
    - Fundus — rounded upper portion, above the entrance of the tubes.
    - Body — portion below fundus, above isthmus.
    - Cervix — lower and smaller portion which extends into vagina.
  - **Three Coats**
    - External, or serous, derived from peritoneum, covers intestinal surface and anterior surface to beginning of cervix.
    - Muscular
      - Circular layer
      - Longitudinal layer
      - Spiral layer
      - Interlaced in every direction.
    - Mucous membrane, lines the uterus.
  - **Blood-vessels**
    - Uterine arteries from hypogastrics.
    - Ovarian arteries from aorta.
    - Remarkable for tortuous course and frequent anastomoses.
  - **Ligaments**
    - Broad, or lateral — two layers of serous membrane.
    - Anterior — peritoneal fold between bladder and uterus.
    - Posterior — peritoneal fold behind the uterus.
    - Round — two fibromuscular cords.
    - Utero-sacral — two partly serous, partly muscular, ligaments.
  - **Function** — To receive ovum, and if it becomes fertilized to retain it until developed and then to expel it.
- **Vagina**
  - Extends from uterus to vulva.
  - **Coats**
    - Internal mucous lining arranged in rugæ.
    - Layer of submucous tissue.
    - Muscular coat.
  - **Location** — Placed in front of rectum, behind bladder.

- **External Genitals**
  - **Mons pubis** — a cushion of areolar, fibrous, and adipose tissue, in front of pubic symphysis, covered with skin and after puberty with hair.
  - **Labia majora** — two folds that extend from the mons pubis to within an inch of the anus.
  - **Labia minora** — two folds situated between the labia majora.
  - **Clitoris** — small body, situated at apex of the triangle formed by junction of labia minora. Well supplied with nerves and blood-vessels.
  - **Vestibule** — Cleft between the labia minora.
  - **Hymen** — fold of mucous membrane that surrounds vaginal orifice.
  - **Glands** — Greater vestibular — oval bodies situated on either side of the vagina.
- **Physiology of generative organs**
  - **Function**
    - Formation and development of ovum.
    - Retention and sustenance of fecundated ovum until able to live outside of body. Expulsion of fetus.
  - **Puberty** — Age at which sexual organs become matured and functional. Girl changes to woman.
  - **Ovulation**
    - Process of development and maturation of follicle and ovum, and discharge of ovum.
  - **Menstruation**
    - A flow of blood from the uterus. Occurs on an average every twenty-eight days. Extends from puberty (14 years) to the menopause, or climacteric (about 45 years). This represents the child-bearing period of a woman's life.
    - Changes in connection with menstrual cycle
      1. Premenstrual period, usually five to six days preceding menstruation.
      2. Period of degeneration or menstruation, usually four or five days.
      3. Post menstrual period, usually two to three days.
      4. Interval, about fourteen days.
  - **Menopause** — Physiological cessation of the menstrual flow.
- **Mammary Glands**
  - **Function** — To secrete milk to nourish infant.
  - **Location**
    - Extend from second to sixth rib and from sternum to arm-pit.
  - **Structure**
    - Outer surface convex — papilla projects from center called nipple — contains openings of milk ducts. Nipple surrounded by areola.
      1. Consists of connective tissue framework which divides the gland into about twenty lobes.
      2. Lobes are subdivided into lobules.
      3. Lobules are made up of terminal tubules of the duct.
      4. Each lobe possesses its own excretory duct, which is called lactiferous and is sacculated.
  - **Blood-vessels**
    - Axillary.
    - Internal mammary.
    - Intercostal.

- **Mammary Glands**
  - **Nerves** — derived from cutaneous branches of fourth, fifth, and sixth thoracic nerves.
  - **Development**
    - Primary development and later functioning suggest an intimate connection between these glands, the uterus, ovaries, and pituitary body.
    - Formerly thought functional development that follows conception was probably due to hormone produced by mature corpus luteum. Recent experiments on animals seem to indicate that these effects are readily produced by pituitary hormone.
  - **Secretion of Milk**
    - Water, Salts, Sugar — Secreted from blood.
    - Proteins, Fat — Formed by disintegration of cells lining lactiferous tubules.

Colostrum — Thin, yellowish fluid secreted during first few days of lactation.

- **Milk**
  - **Composition**

	Human	*Cow's*
Water	88.4%	88.1%
Proteins	1.5%	3.2%
Fat	3.3%	3.9%
Lactose	6.5%	4.9%
Salts	0.3%	0.9%

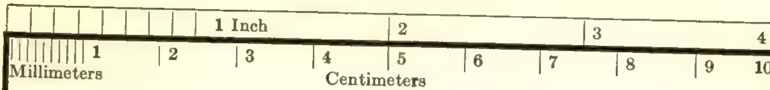
  - **Differences**
    - Different relative proportions.
    - Difference in proteins
      - Human: Caseinogen $\frac{1}{3}$. Lactalbumin $\frac{2}{3}$.
      - Cow's: Caseinogen $\frac{5}{6}$. Lactalbumin $\frac{1}{6}$.
    - Difference in curds
      - Human — small flocculi.
      - Cow's — heavy curds.
    - Difference in reaction
      - Human — practically neutral, pH 7.0 to 7.2.
      - Cow's — slightly acid, pH is 6.6 to 6.8.
    - Bacterial count
      - Human — sterile.
      - Cow's — sterile, but due to handling it undergoes, it contains large number of bacteria.
    - Germicidal power
      - Human — Antitoxins and antibacterial substances found in mother's blood.
      - Cow's — May have germicidal value but it is lost by time milk reaches infant.

Parturition — 280 days from beginning of last mensis.

- Stages of labor
  - Stage of dilation.
  - Stage of descent.
  - Placental stage.

Involution — Return of uterus to approximately normal size following parturition.

Metric System



The area of the figure within the heavy lines is a hundred square centimeters. A cube, one of whose sides has this area, would contain a thousand cubic centimeters or a liter. A liter of distilled water at 4° C. weighs a *kilogram*.

A liter is 2.11 pints or 33.81 ounces. A pint is 0.473 of a liter. (Liquid measure.)

A liter is 1.76 pints. A pint is 0.568 liter. (Dry measure.)

A liter is 61.027 cu. in.

A cu. cm. is .061 cu. in.

A milliliter is $\frac{1}{1000}$ of a liter.

A milliliter of water at 4° C. weighs a gram.

The smaller figures in dotted lines represent the areas of a square centimeter and of a square inch.

Square Inch

Square Centimeter

1 Millimeter	=	.039 inch.
1 Centimeter	=	.393 inch.
1 Decimeter	=	3.937 inches.
1 Meter	=	39.370 inches.

1 Milligram	=	.015 grain.
1 Centigram	=	.154 grain.
1 Decigram	=	1.543 grains.
1 Gram	=	15.432 grains.
1 Dekagram	=	154.323 grains.
1 Hektogram	=	1543.235 grains.
1 Kilogram	=	15432.350 grains.
1 Kilogram	=	35.274 ounces.
1 Kilogram	=	2.204 pounds.

Avoirdupois weights are used in weighing the organs of the body. One ounce avoirdupois = 28.35 grams. For the sake of simplicity in converting figures in the text from one system to the other, we have assumed

1 in. to equal 25,000 microns (μ).
1 in. to equal 25 mm.
1 in. to equal 2.5 cm.
1 cm. to equal $\frac{2}{5}$ in.
1 cc. to equal 15 minims.
30 gm. to equal 1 oz. (dry or liquid measure).
30 cc. to equal 1 oz. (dry or liquid measure).

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GLOSSARY

Ac′etone. $(CH_3)_2CO$. A liquid found in the urine of individuals suffering from defective metabolism — acetonuria or ketonuria.

Agglutina′tion. The adhesion or clumping of cells, and loss of motility in the case of motile cells, when suspended in fluid containing a suitable agglutinin.

Agglu′tinin. A substance which produces agglutination by its action on the surface of cells.

Ag′gregated. Formed by a collection of several bodies; crowded.

Ag′minated. Arranged in clusters, grouped together, as the agminated glands of Peyer in the small intestine.

Al′anin. Amino-propionic acid $C_2H_4NH_2COOH$.

Albu′mins. Thick, viscous substances containing nitrogen, that are soluble in water, dilute acids, dilute salines, and concentrated solutions of magnesium sulphate and sodium chloride. They are coagulated by heat and strong acids. Examples are: egg albumin and serum albumin of blood.

Al′kalies. The alkalies are the bases of sodium, potassium, ammonium, etc.; they give very strong basic action.

Ametro′pic. Relating to ametropia (any abnormality of refractive surfaces or media of the eye).

Amito′sis. Fission or direct cell-division. Same as akinesis.

Amphib′ia. A class of vertebrate animals that is able to live both on land and in water, as the frog.

Ampul′la. The dilated part of a canal.

Amylop′sin. A pancreatic enzyme which changes starch to maltose. Same as diastase and amylase.

Ana′ërobe. Any microörganism which has the power to live without free air or oxygen.

Anaërob′ic. Thriving best without free air.

Anastomo′sis. Communication of branches of vessels with one another.

An′ilin. $C_6H_5NH_2$. A colorless oily liquid obtained from coal tar and indigo.

An′tigens. Substances which cause production of antibodies; toxins, agglutinogens, opsonins, etc.

Antineurit′ic. Counteracting neuritis.

Antirachit′ic. Counteracting rickets.

A′pex, pl. **Ap′ices.** The top or pointed extremity of anything.

Arboriza′tion. A branching distribution of veinlets or of nerve filaments, especially the branched terminal ramifications of a nerve axon.

Ar′gon. An element, molecular weight 39.9. An inert gaseous constituent of atmosphere.

Arrecto′res Pilo′rum. The minute involuntary muscles of the skin, whose contraction produces goose-flesh. Also known as arrector and pilomotor muscles.

At′las. The first cervical vertebra by which the head articulates with the spinal column, so called because it supports the head as Atlas was fabled to support the world on his shoulders.

Au′tacoid. Any one of the internal secretions.

Automat′ic. Self-acting; spontaneous. Same as autonomic.

Autonom′ic. Performed without the will; spontaneous. Same as automatic.

Auton'omy. Independence; the condition of having independent functions, limitations, and laws.

Au'tosome. Any pair of chromosomes except the sex chromosomes.

Avi'taminosis. This term signifies the physiological or pathological conditions which arise from deficiency or complete absence of vitamins from the food.

Az'ygos. Without a fellow; hence, unpaired, single.

Bas'al Metab'olism. Rate of energy metabolism 12 to 18 hours after eating, of a person at rest as measured by calorimeter.

Ba'sic. Pertaining to or having the properties of a base. Capable of neutralizing acids.

Bas'ilar. Pertaining to the base of an object; *e.g.*, basilar artery located at the base of the brain.

Ba'sophile. Leucocytes which stain with basic dyes.

Benzo'ic a'cid. A white crystalline acid $C_7H_6O_2$.

Bicip'ital. Referring to the biceps.

Blas'tocyst. Modified blastula. In the blastocyst, the embryo is developed from a disk of cells suspended within the cavity.

Blas'toderm. First layer of cells formed in the embryo. Gives rise to the ectoderm, mesoderm, and entoderm.

Blas'tomeres. Cells of early embryonic subdivision, forming the morula.

Blas'tula. Hollow sphere of embryonic cells.

Brachiocephal'ic. Of or pertaining to both the upper arm and head; as the brachiocephalic (innominate) artery and veins.

Brit'tle. Easily broken.

Bulb. A rounded mass, organ, or part. The spinal bulb or medulla oblongata; the bulb of the eye or eyeball.

Butyr'ic Acid. C_3H_7COOH. A colorless liquid having a strong rancid smell and acrid taste.

But'tock. The gluteal prominence, or a lateral half of the same.

Caffe'in. An alkaloid, stimulant, diuretic.

Cal'cify. Harden by deposit of salts of calcium; petrify.

Cal'orie. The Calorie (Cal.) is the amount of heat required to raise the temperature of one kilogram of water through 1° C. or one pound of water 4° F. The small calorie is the amount of heat required to raise the temperature of one gram of water through 1° C.

Cal'culus, pl. **Cal'culi.** A stone.

Ca'lyx, pl. **Cal'yces.** Small, cup-like divisions of the pelvis of the kidney.

Canalic'ulus, pl. **Canalic'uli.** A small channel, or vessel.

Ca'nine. Pointed like the tusks of a dog. Name given to the third tooth on each side of the jaw.

Car'dia. The heart. The upper orifice of the stomach.

Car'diograph. Instrument used to obtain tracing showing the force and form of the heart's movements.

Casein'ogen. The curd separated from milk by the addition of rennet, constituting the basis of cheese.

Castra'tion. Removal of the testes in the male, or the ovaries in the female.

Catacrot'ic. Referring to a pulse tracing in which the down stroke shows one or more upward marks.

Catab'olism. The processes in cells by means of which complex substances are rendered more simple and less complex. The opposite of anabolism. Sometimes spelled katabolism.

Catal'ysis. A changing of the speed of a reaction, produced by the presence of a substance which does not itself enter into the final product.

Cat'alyzer. A substance which acts by catalysis, *i.e.*, modifies the speed of chemical processes.

Ce'cum. Any blind pouch or cul-de-sac. The first part of the large intestine, below the ascending colon.

Ce'liac. Pertaining to the abdominal cavity. A hollow.

Celluli'tis. Inflammation of connective tissue. Most common form is inflammation of superficial fascia.

Centrif'ugal. Flying off or proceeding from the center.

Centrip'etal. Tending or moving toward the center. Opposed to centrifugal.

Ceru'men. Ear-wax.

Chal'one. An inhibitory or antagonistic hormone.

Chemo'-recep'tors. Term applied to receptors that are stimulated by suitable concentrations of definite substances.

Chi'asm. A crossing or decussation; especially that of the fibers of the optic nerve.

Chlo'roplast. A plastid containing chlorophyll, developed only in cells exposed to the light. They are minute flattened granules, usually occurring in great numbers in the cytoplasm near the cell wall, and consist of a colorless ground substance saturated with chlorophyll.

Choa'næ. The posterior nares. Funnel-shaped.

Choles'terol. A sterol, $C_{27}H_{43}OH$, found in small quantities in the protoplasm of all cells, especially in nerve tissue, blood cells, and bile. Same as cholesterin.

Chor'da Tym'pani. The tympanic cord, a branch of the facial, or seventh cranial nerve, which traverses the tympanic cavity and joins the gustatory, or lingual, nerve.

Chor'dæ Tendin'eæ. Tendinous cords joining the papillary muscles of the heart with the valves.

Chro'maffin. Certain cells occurring in the adrenal, coccygeal, and carotid glands, along the sympathetic nerves and in various organs, take up and stain strongly with chrome salts, hence called chromaffin. The whole system of such tissue throughout the body is named the chromaffin or chromophil system.

Chro'matin. Portions of the nucleus which stain deeply with basic dyes, *e.g.*, methylene blue.

Chromophil'ic. Staining readily.

Chro'mosome. Segment of chromatin. Described by T. H. Morgan "as a linear aggregate of genes."

Chro'naxie. Minimum time during which an electric current of twice the rheobasic strength must be applied in order to excite response.

Cica'trix. The mark, or *scar*, left after the healing of a wound.

Cleavage. The process of division of the fertilized ovum before differentiation into layers occurs. Same as segmentation.

Climacter'ic. The turn of life, menopause.

Clon'ic. Pertaining to or of the nature of spasm, in which rigidity and relaxation succeed each other.

Coeffi'cient. In chemistry a number or figure put before a chemical formula to indicate how many times the formula is to be multiplied.

Col'loid. A state of matter in which particles having a diameter of $.1\,\mu - .001\,\mu$ are suspended in a dispersing medium, water, etc.

Com'missure. A joining. A bundle of nerve fibers passing from one side of the brain or spinal cord to the other side. The corner or angle of the eyes or lips.

Complemen'tal. Making complete; accessory.

Compo'nent. A constituent part of anything. A series of neurons forming a special system (afferent or efferent).

Com'pounds. Made of two or more parts or ingredients. Any substance made up of two or more kinds of materials. In chemistry a substance which consists of two or more chemical elements in union.

Concentra'tion. The process of increasing the strength of a fluid by evaporation of the liquid or volatile ingredients.

Con'cept. A general notion of a thing in the mind.

Congen'ital. Born with a person, existing from or before birth.

Conjuncti'va. The delicate membrane that lines the eyelids and covers the eyeball.

Conservation. Preservation.

Contig'uous. Adjacent; near, in actual contact.

Convec'tion. A process of transfer or transmission, as of heat or electricity. The term "convection currents" is applied to currents of air produced by differences in temperature and density. Warm air expands, becomes less dense, and is forced upward by the cooler air, which is heavier, and sinks down. In this way convection currents are established.

Cor'onary. A term applied to vessels, ligaments, and nerves which encircle parts like a crown, as the coronary arteries of the heart.

Cor'pus Lu'teum, pl. **Corpora Lutea.** Yellow body, in the ovary taking the place of a Graafian follicle which has discharged its ovum.

Correla'tion. The interdependence of organs or functions; the reciprocal relations of organs.

Crena'ted. Notched on the edge.

Crep'itate. To make a crackling sound.

Crib'riform. Perforated like a sieve.

Cru'ra Cer'ebri. Pillars of the cerebrum.

Cu'mulus Oöphor'us. A term applied to a mass of cells clinging to the ovum where it is set free from the ovary. Same as discus proligerus and ovarian mound.

Cyano'sis. Blueness of the skin, resulting from insufficient oxygenation of the blood.

Cysti'tis. Inflammation of the bladder.

Deaminiz'ing. Liberation of ammonia from an amid.

Decomposi'tion. The separation of compound bodies into their constituent parts or principles. Any ordinary process of decay, especially putrefaction.

Decussa'tion. To cross in the form of the letter X.

Dehydra'tion. Removal of water from a substance or compound.

Delir'ium Cor'dis. Violent, tremulous beating of the heart.

Del'toid. Having a triangular shape; resembling the Greek letter Δ (delta).

Depres'sor. Depressing or retarding vasomotor activity.

Dial'ysis. The passage through a permeable membrane of a substance in solution.

Diapede'sis. Passing of the red blood cells through vessel walls without rupture.

Diastol'ic. Pertaining to the diastole.

Diath'esis. A congenital condition of the system which renders it peculiarly liable to some diseases.

Dichot'omous. Divided into two. Pertaining to or consisting of a pair or pairs.

Diges'tion. The process of converting food into substances that can be absorbed and assimilated. The subjection of a substance to prolonged heat and moisture, so as to disintegrate and soften it.

Disc. A circular or rounded flat plate or organ. A medicated lamella or wafer.

Dis'cus Prolig'erus or germ disc. A term applied to a mass of cells clinging to the ovum when it is set free from the ovary. More recent terms are ovarian mound and cumulus oöphorus.

Distilla'tion. The act of distilling or of falling in drops. The operation of driving off gas or vapor from volatile liquids or solids, by heat, in a retort or still, and the condensation of the products as far as possible by a cooler receiver.

Diure'sis. Increased secretion of urine.

Dor'sum, pl. **Dorsa.** The back. An upper surface.

Dyspha'gia. A difficulty in swallowing.

Ectop'ic. Characterized as being out of place.

Ectop'ic Gesta'tion. The name given to pregnancy, when the fecundated ovum, instead of entering the uterus, remains either in a Fallopian tube or the abdominal cavity.

Ede'ma. A swelling due to effusion of serous fluid into the areolar tissue.

Effec'tor. A nerve end-organ which serves to distribute impulses which activate muscle contraction and gland secretion.

Electrons. Negative electrical units which with positive electrical units constitute atoms.

El'ements. Any one of the primary parts or constituents of a thing. In chemistry a substance which cannot be separated into more simple substances by chemical means.

Em'bolus. A portion of a blood clot which has been formed in one of the larger vessels, and has afterward been forced into one of the smaller vessels, where it may act as a wedge.

Em'bryo. The ovum and product of conception up to about the third month, when it becomes known as the fetus.

Emmetro'pic. Characterized by normal vision.

Empir'ical. Relating to a knowledge of medicine obtained by experience alone.

Emul'sion. A mixture of two immiscible fluids, where one is scattered through the other in the form of finely divided globules.

Endem'ic. Occurring frequently in a certain district.

En'docrine. Pertaining to internal secretions.

Endog'enous. Originating within the organism; not exogenous.

Endoneu'rium. The connective tissue sheath of the individual nerve fibers in a funiculus.

En'ergy. Capacity or ability to do work; power to produce motion, to overcome resistance, and to effect physical changes.

Equilib'rium. That condition of rest which results when all the forces acting in a body are equally opposed. In physiology it signifies the harmonious action of the organs of the body, as in standing.

Evagina'tion. A protrusion of some part or organ.

Evapora'tion. The act of resolving into vapor. In order to produce vapor, heat is necessary and, if not supplied, it is taken from near objects. Thus the heat necessary for the evaporation of perspiration is taken from the body.

Exog'enous. Developed outside the body.

Exophthal'mic. Pertaining to or characterized by abnormal protrusion of the eyeball.

Ex'terocepters. Term applied to receptors which are stimulated by influences outside the body, *e.g.*, pain spots, heat spots, cold spots, etc. Same as exterorecepters.

Ex'udate. A fluid or semifluid deposited in the tissues, or in a cavity, as the result of some vital process.

Fal'ciform. Sickle-shaped.
Fascic'ulus, pl. **Fascic'uli.** A bundle of close-set nerve fibers.
Fecunda'tion. Fertilization. Impregnation.
Fenes'trated. Having window-like openings. Perforated.
Fe'tus. The child in the womb from the second month of pregnancy till birth.
Fibril'la, pl. **Fibril'læ.** A little fiber, or filament.
Fibrilla'tion. The quality of being fibrillæ. Muscular tremor. A condition of muscular action, particularly of the heart muscle, in which the individual fibers take up their own independent action, producing an incoördinate contraction.
Fim'bria, pl. **Fim'briæ.** A border or fringe.
Flat'ulence. Distension due to generation of gases in the stomach and intestines.
Funic'ulus, pl. **Funic'uli.** The umbilical cord. The spermatic cord. One of the bundles of nerve fibers of which a nerve trunk is made up.

Gam'ete. Sexual germ cells.
Gan'glion, pl. **Gan'glia.** A collection of neurons outside the central nervous system.
Gang'lionec'tomy. Excision of a ganglion.
Gas'troepiplo'ic. Pertaining to the stomach and the greater omentum.
Gas'trula. Embryonic stage following the blastula, formed of two layers of cells.
Gene. Inheritance determiner, component of chromosome.
Gen'erative. Pertaining to generation, or propagation. Connected with or resulting from the process of begetting.
Gen'ito-u'rinary. Relating to the genital and urinary organs.
Gesta'tion. The act or condition of carrying young in the womb from conception to delivery. Pregnancy.
Gli'a. The neuroglia.
Glob'ulins. Protein substances somewhat similar to the albumins, but differing in their solubility.
Glomer'ulus. A term applied to the ball-like tuft of capillaries which is surrounded by the glomerular capsule of a renal tubule of the kidney. A botanical term signifying a small, dense, roundish cluster.
Glu'cose. Grape-sugar or dextrose, $C_6H_{12}O_6$. Found in honey, fruit, etc.; also in blood, lymph, and diabetic urine.
Glute'i, pl. of **Glute'us.** The muscles forming the buttocks.
Gly'cocoll. Gelatin-sugar or amino-acetic acid (CH_2NH_2COOH). Any substance of the group to which glycocoll belongs.
Gly'cogen. A form of animal starch ($C_6H_{10}O_5$). Found in the liver, muscles, and other tissues.
Glycogen'esis. The production of glycogen.
Glycogenol'ysis. Splitting of glycogen into glucose.
Glycol'ysis. Splitting of glucose into carbon dioxide and water.
Glycosu'ria. The presence of sugar in the urine.
Gon'ad. Gamete-producing gland; *e.g.*, testis, ovary.
Graaf'ian Fol'licles, or Vesic'ular Ova'rian Fol'licles. A term applied to the sacs in the ovaries, which contain the ova, or cells.
Granula'tions. Grainlike, fleshy bodies that form on the surface of wounds and ulcers.
Grav'ity. Weight; tendency toward the center of the earth.

Hem'atin. A non-protein substance, which contains iron.
Hemocytom'eter. Instrument used in counting blood corpuscles.
Hemoglo'bin. A conjugated protein found in the red cells of the blood; it consists of a protein named globin and a non-protein named hematin.

Hemophil'ia. Strong tendency to bleed immoderately from any insignificant wound, or even spontaneously. It is usually hereditary.

Hemorrhoi'dal. Pertaining to hemorrhoids, small tumors of the rectum, which frequently bleed.

Hi'lum, sometimes written **Hi'lus.** It is the depression, usually on the concave side of a gland, where vessels and ducts enter or leave.

Homeos'tasis. Constancy of the internal environment.

Homoge'neous. Of the same kind or quality throughout; uniform in nature; the reverse of heterogeneous.

Horizon'tal. Of, at, the horizon; parallel to the plane of the horizon, at right angles to the vertical.

Hor'mone. A chemical substance which, produced in one organ and carried by the blood to another organ, stimulates secretion or some other activity. The active principle of an internal secretion.

Hydroceph'alus. An excess of fluid in the brain, accompanied by an enlarged head and mental weakness.

Hyperglyce'mia. An abnormal amount of sugar in the blood.

Hyperthy'roidism. A condition due to excessive functional activity of the thyroid.

Hyperton'ic. Excessive tonicity, strength, or tension. Applied to solutions having a greater osmotic pressure than blood serum. Same as hyperosmot'ic.

Hypoth'esis. Supposition made as basis for reasoning, without reference to its truth, or as starting point for investigation; unproved assumption.

Hypoton'ic. Decreased tonicity or tension. Applied to solutions having a lower osmotic pressure than blood serum. Same as hyposmot'ic.

Il'eum. The last portion of the small intestine.

Il'ium, pl. **Il'ia.** The upper part of the os innominatum.

Immis'cible. Not capable of being mixed.

In'dican. Potassium indoxyl sulphate, found in sweat and urine. It is derived from the indol formed in the intestines during putrefaction, and from putrefaction of body tissues as in abscess formation.

In'dol. A crystallizable body, C_8H_7N, from indigo, feces, etc.; one of the products of intestinal indigestion.

Inflamma'tion. An abnormal condition characterized by pain, heat, redness, and swelling.

In'guinal. Pertaining to the groin.

Inocula'tion. The injection of virus into any part of the body, experimentally or for preventive or curative purposes.

Inos'culate. To join by direct union or by anastomosis.

Insemina'tion. Process of placing spermatozoa for contact with ova.

In'sulate. To isolate or separate from surroundings.

In'sulin. Name given to an hormone of the internal secretion of the pancreas.

Interocep'tors. Term applied to nerve-endings located in the viscera, which are stimulated by conditions in this region, *e.g.*, taste receptors, receptors in stomach, etc. Same as interoreceptors.

Intersti'tial. Connective tissue framework of glands.

Invag'inate. To thrust one portion within another portion of the same thing.

Is'chium, pl. **Is'chia.** The lower portion of the os innominatum; that upon which the body is supported in a sitting posture.

Isoagglu'tinin. An agglutinin in serum which can agglutinate the red blood cells of other individuals of the same species.

Isoagglutin'ogen. A substance in blood cells which stimulates the action of agglutinins.

Isohemol′ysin. An hemolysin which can dissolve the red blood cells of other individuals of the same species.

Isoton′ic. Having the same osmotic pressure as the blood serum. Same as isosmot′ic.

Ketogen′ic. Producing or tending to produce acetone bodies.

Kryp′ton. A gas found in the atmosphere.

Ky′mograph. Cylinder revolving at uniform rate, upon which a writing point traces the variations of pulse, of respiration, etc.

Kypho′sis. Hunch-back.

Lacta′tion. The secretion of milk.

Lacu′na, pl. **Lacu′næ.** A minute hollow space.

Lambdoi′dal. Resembling the Greek letter lambda.

Lamel′la, pl. **Lamel′læ.** A thin plate, or layer.

Lam′ina. A thin plate; a germinal layer.

Laryn′goscope. The instrument by which the larynx may be examined in the living subject.

Lens. A transparent substance, usually glass, bounded by two curved surfaces, or by one curved and one plane. There are two general classes of lenses: concave, which are thinner at the center than at the edges; and convex, which are thicker at the center than at the edges.

Lig′ature. A thread or wire for tying a vessel. The act of applying a ligature.

Lin′ea as′pera. A rough longitudinal line on the back of the femur.

Lymphangi′tis. Inflammation of a lymphatic vessel.

Ly′sin. Lysis, to dissolve. An antibody which can dissolve cells, etc.

Macera′tion. The softening of the parts of a tissue by soaking.

Macroscop′ic. That which can be viewed with the naked eye.

Malle′olus, pl. **Malle′oli.** A name given to the pointed projections formed by the bones of the leg at the ankle joint.

Manom′eter. An instrument for measuring the pressure or tension of liquids or gases.

Maras′mus. Progressive wasting and emaciation, especially in young infants.

Matura′tion. Process by which the number of chromosomes in germ cells is reduced one half.

Mechan′ico-recep′tors. Term applied to nerve-endings that are stimulated by mechanical means, *i.e.*, pressure, vibratory impacts, etc.

Meio′sis. Process in maturation during which the members of paired chromosomes are separated.

Mes′enchyme. Part of mesoderm giving rise to vascular and conective tissues.

Mesoco′lon. A duplicature of the peritoneum covering the colon.

Mes′oderm. Middle layer of the early embryo, lying between ectoderm and entoderm.

Microceph′alus. A person with a very small head.

Microdissec′tion. Dissection under a microscope or a magnifying glass.

Mi′cron. One thousandth of a millimeter (0.001 mm.). Symbol, μ.

Mito′sis. Processes of indirect cell division. Same as karyokinesis.

Mix′tures. In medicine, a preparation of various ingredients. From a chemical standpoint a mixture can be made up of either or both elements and compounds. These can often be separated by simple physical means, as filtration or evaporation.

Modi′olus. The central pillar of the chochleæ.

Mononu′clear. Having but one nucleus.

Mo'tor. Producing or subserving motion. A muscle, nerve, or center that affects or produces movement.

Mu'cin. A glycoprotein, a constituent of mucus.

My'elocyte. A bone marrow cell giving rise to granulocytes.

Myogen'ic. Originating in muscular tissue.

Myoneu'ral. Pertaining to both muscle and nerve.

My'osin. A globulin, chief protein substance of muscle.

Myxede'ma. A disease due to deficient secretion of the thyroid gland; it is characterized by subnormal temperature, dryness and loss of hair, edema of the subcutaneous tissue, and mental dullness.

Na'ris, pl. **Na'res.** A nostril.

Ner'vus Er'igens, pl. **Ner'vi Erigen'tes.** A nerve fiber supplying the bladder, genitals, and rectum; derived from the second and third sacral nerves.

Neurasthen'ic. The name for a group of symptoms resulting from some functional disorder of the nervous system, with severe depression of the vital forces. It is usually due to prolonged and excessive expenditure of energy, and is marked by tendency to fatigue, lack of energy, pain in the back, loss of memory, insomnia, constipation, loss of appetite, etc.

Neurogen'ic. Originating in nerve tissue.

Nic'otine. An acid, colorless, fluid base obtained from tobacco; exceedingly poisonous.

Norm. A rule or standard.

No'tochord. The primitive back bone in the embryo.

Nucle'olus, pl. **Nucle'oli.** A smaller nucleus within the nucleus.

Nu'cleus, pl. **Nu'clei.** A minute vesicle embedded in the cell protoplasm.

Nu'cleus Cunea'tus. A group of nerve cells in the medulla in which the fasciculus cuneatus of the spinal cord ends.

Nu'cleus Gra'cilis. A group of nerve cells in the medulla, in which the fibers of the fasciculus gracilis of the spinal cord end.

Odon'toid. Tooth-like.

Ol'igu'ria. Deficient secretion of the urine; abnormally diminished frequency of micturition.

Oöcyte. The mother cell of an ovum.

Op'timal. Most suitable or favoring.

Organ'ic. Pertaining to an organ or organs. Having an organized structure. Arising from an organism. In chemistry, a compound containing carbon.

Os, pl. **O'ra.** A mouth.

Os, pl. **Os'sa.** A bone.

Os Cox'æ, pl. **Os'sa Cox'æ.** The hip bone, or os innominatum.

Osmo'sis. The passage of fluids and solutions, separated by a membrane, or other porous septum, through the partition, so as to become mixed or diffused through each other.

Os'sa Innomina'ta, pl. of **Os Innomina'tum.** "Unnamed bones." The irregular bones of the pelvis, unnamed on account of their non-resemblance to any known object.

Os'teoblasts. The cells forming or the developing into bone.

Os'teoclast. A large cell found in the bone marrow, believed to be capable of absorbing bone.

Osteogenet'ic. Pertaining to the formation of bone.

O'toliths. Particles of calcium carbonate and phosphate found in the internal ear.

O'vum, pl. **O'va.** The female germ cell.

Oxida'tion. As usually used, the union of oxygen with metals and nonmetals, more technically oxidation is removing electrons.

Papil'la, pl. **Papil'læ.** A small eminence.

Parturi'tion. The act of giving birth to young.

Ped'icle. A stalk.

Pedun'cle. A narrow part acting as a support.

Perikar'yon. The cell body as distinguished from the nucleus and processes.

Perineu'rium. The sheath which encloses each funiculus of a nerve fiber.

Perpendic'ular. At right angles to the plane of the horizon; erect, upright, in standing position.

Phimo'sis. Tightness of the foreskin, so that it cannot be drawn back from over the glans; also the analogous condition in the clitoris.

Phlebot'omy. The opening of a vein; venesection.

Phona'tion. Utterance of vocal sounds.

Phos'phate. Any salt of phosphoric acid.

Phren'ic. Pertaining to the diaphragm.

Phys'ical. Pertaining to nature, or to the body.

Phys'ics. The science of the laws and phenomena of nature, but especially of the forces and general properties of matter.

Po'lar. Of or pertaining to a pole.

Polar'ity. Tendency of a body to place its mathematical axis in a particular direction.

Potential'ity. State or quality of being possible.

Precip'itins. Antibodies which are capable of producing precipitation.

Pres'sor. Inciting or increasing vasomotor activity.

Prona'tion. The turning of the hand with the palm downward.

Prona'tor. The group of muscles which turn the palm of the hand downward.

Pro'priocep'tors. Term applied to nerve-endings located in deeper regions of the body wall, stimulated by processes within the body, and indirectly by environmental forces, pressure receptors of muscles, tendons, ligaments, etc. Same as proprireceptors.

Prosecre'tin. The precursor of secretin, thought to be contained in epithelial cells of the duodenum, and to be converted into secretin on hydrolysis with acids.

Prox'imal. Nearest the trunk, center, or median line.

Pseudopo'dium. A protrusion of the substance of an ameba or an ameboid cell, as in locomotion.

Psy'chical. Pertaining to the mind.

Pu'berty. Sexual maturity in the human race; the age at which functional gametes are formed.

Pu'bus, pl. **Pu'bes.** The hairy region above the genitals, also used for os pubis, the portion of the os innominatum forming the front of the pelvis.

Pyogen'ic. Producing pus.

Pyrex'ia. Elevation of temperature; fever.

Quadrigem'inal. Fourfold, or in four parts.

Quies'cent. Motionless, inert, silent, dormant.

Radia'tion. The act of spreading outward from a central point. The diffusion of rays of light.

Ra'dio-recep'tors. Term applied to nerve-endings which are stimulated by the effects of radiant energy, heat receptors, cold receptors, etc.

Râle. A rattling, bubbling sound attending the circulation of air in the lungs, different from the murmur produced in health.

Ramisec'tion. Cutting the rami communicantes of the sympathetic nervous system.

Rec'tus, pl. **Rec'ti.** Straight. A name given to muscles of the eye and abdomen.

Reduc'tion. As usually used, means removing oxygen; more technically, reduction is adding electrons.

Reflec'tion. The return of rays, beams, sound, or the like from a surface. Reflection of light is of two kinds, *regular* and *diffused.* When a beam of light enters a darkened room through a small opening and strikes a mirror, a reflected beam will be seen traveling along some definite path. This is called *regular reflection.* Should the light, however, fall on a piece of white paper, it would be reflected and scattered in all directions. This is called *diffused reflection,* and is caused by the inequalities of the reflecting surface. All rough surfaces, as well as dust and moisture in the atmosphere, serve to diffuse light. If this were not the case, it would be dark everywhere except in the direct path of light from some luminous body.

Refrac'tion. The bending or deviation in the course of rays of light in passing obliquely from one transparent medium into another of different density.

Regurgita'tion. The casting up of undigested food. A backward flowing of the blood through the left atrioventricular opening on account of imperfect closure of the mitral valve.

Resil'iency. The act of leaping, or springing back; the act of rebounding.

Retic'ular. Resembling a *small net.*

Retrogres'sion. Degeneration. Catabolism.

Ru'gæ, pl. of **Ruga.** A term applied to the folds in the mucous membrane, especially of the stomach and vagina.

Saliva'tion. An excessive secretion of saliva.

Salt. Sodium chloride. Chemically a salt is a substance containing the metal from a base and the acid radical from an acid.

Saponifica'tion. Conversion into soap.

Sciat'ic. Pertaining to the ischium.

Secre'tagogue. An agent which stimulates secretion.

Segmenta'tion. The process of division of the fertilized ovum before differentiation into layers occurs. The same as cleavage.

Sel'la tur'cica. A saddle-shaped depression on the upper surface of the sphenoid bone; it contains the hypophysis (pituitary body).

Se'men. Fluid secreted by various parts of the male reproductive organs; contains spermatozoa.

Ses'amoid. Resembling a grain of sesame. A term applied to the small bones situated in the substance of tendons, near certain joints.

Si'nus. A recess, cavity, or hollow space. A dilated channel for venous blood; found chiefly in the cranium. An air cavity in one of the cranial bones, especially the ethmoid, frontal, maxilla, and sphenoid sinuses.

Ska'tol. A strong-smelling crystalline substance from human feces. It is produced by the decomposition of proteins in the intestines.

Solute'. A substance dissolved in a solution.

Sol'vent. Dissolving; effecting a solution. A liquid that dissolves or is capable of dissolving.

Somat'ic. Pertaining to the body.

Specif'ic grav'ity. By specific gravity is meant the comparison between the weight of a substance and the weight of an equal volume of some

other substance taken as a standard. The standards usually referred to are air for gases, and water for liquids and solids. For instance, the specific gravity (sp. gr.) of carbon dioxide (air standard) is 1.5, meaning that it is 1.5 times as heavy as an equal volume of air. Again the specific gravity of mercury (water standard) is 13.6, meaning that mercury is 13.6 times as heavy as an equal volume of water. The specific gravity of solutions, as a salt solution, will necessarily vary with the concentration.

Sper'matocyte. The mother cell of a spermatozoön.

Sphinc'ter. A circular muscle which contracts the aperture to which it is attached.

Sphygmomanom'eter. Instrument for measuring blood-pressure in the arteries.

Spirom'eter. Instrument for measuring inhaled and exhaled air.

Splanch'nic. Of or pertaining to the viscera.

Stimu'lus, pl. **Stim'uli.** Anything that excites to action.

Sto'ma, pl. **Sto'mata.** A mouth; a small opening.

Sul'phates. Any salt of sulphuric acid.

Summa'tion. Addition, finding of total or sum.

Su'ture. That which is sewn together, a seam; the seam uniting bones of the skull.

Syn'apse. Interlacing of terminal arborization of nerves.

Syner'gic. Acting together in coöperation or harmony.

Synon'ymous. Having a similar meaning.

Ten'do Achil'lis. "Tendon of Achilles." The tendon attached to the heel, so named because Achilles is supposed to have been held by the heel when his mother dipped him in the river Styx to render him invulnerable.

Tet'any. A disease characterized by painful tonic and symmetric spasm of the muscles of the extremities.

The'nar. Mound at base of thumb.

Thermogen'esis. The production of heat, especially the process of generating heat within the animal body.

Thermol'ysis. Dissociation by means of heat. The dissipation of bodily heat.

Thermotax'is. The normal adjustment of the bodily temperature. The movement of organisms in response to heat.

Throm'bus. Name given to a clot formed in a blood-vessel.

Thyrox'in. A crystalline compound, $C_{11}H_{10}O_3NI_3$, isolated from the thyroid gland, and having the properties of thyroid extract.

Tone. The normal degree of vigor or tension; a healthy state of a part.

Trabec'ulæ. A term applied to prolongations of fibrous membranes which form septa, or partitions.

Trape'zius. A name given to the two upper superficial muscles of the back, because together they resemble a trapezium, or diamond-shaped quadrangle.

Unicel'lular. Composed of a single cell.

Vac'uoles. Any space or cavity formed in the protoplasm of a cell.

Vac'uum. A space from which the air has been exhausted.

Ve'na Co'mes, pl. **Ve'næ Com'ites.** A deep vein following the same course as the corresponding artery.

Ve'na Com'itans, pl. **Ve'næ Comitan'tes.** Same as Vena Comes.

Ver'miform. Worm-shaped.

Ver'nix Caseo'sa. The fatty substance found on the new-born infant, which is secreted by the sebaceous glands of the skin.

Ver′tebra, pl. Ver′tebræ. The bones of the spine.
Vis′cid. Glutinous or sticky.
Viscos′ity. The quality of being viscous.
Vis′cous. Sticky or gummy; viscid.
Vitamin. Substance existing in minute quantities in natural foods, necessary for growth and health.
Vit′iated. Impairment of quality; debased, corrupted.
Vo′lar. Pertaining to the palm of the hand or the sole of the foot.

Xerophthal′mia. Conjunctivitis with atrophy and no liquid discharge, producing a dry and lustreless condition of the eyeball.

Zy′gote. Union of two gametes, beginning a new life cycle.
Zy′mogen. A mother substance or antecedent of an enzyme.

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